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VALIDATION OF NEW GUST DESIGN PROCEDURES FOR MILITARY TRANSPORTS

James K. Spitler

Lockheed-Georgia Company

Prepared for:

Air Force Flight Dynamics Laboratory

November 1973

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Updated gust intensity, proportion of time in turbulence, and design exceedance rate were supplied for this evaluation. Justification of these revised parameters from the TR-70-106 values is given in Reference 2.

The Preliminary (perhaps final) procedure indicates a slightly revised operational flight envelope for the expanded payload missions of the C-130E. The other three models, the C-141A, C-140, and C-5A, have sufficient load margins due to loadings resulting from maneuver criteria to conclude gust analysis at the Preliminary procedure. All aircraft have adequate load margins for the Detailed and Exceedance Design Procedures. The design manual, using power spectral techniques, provides compatible gust design loads as those provided in past gust analysis. Each of the four aircraft have been designed to different gust criteria.

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FOREWORD

This report was prepared by Lockheed-Georgia Company, Marietta, Georgia, under Air Force Contract F33615-73-C-3047. The contract was initiated under Project No. 1367, "Structural Design Criteria," Task No. 136702, "Aerospace Vehicle Structural Loads Criteria." The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Mr. Paul L. Hasty (FBE), Project Engineer.

The work reported in this study was conducted by Lockheed-Georgia Company with Mr. James K. Spitler as principal investigator, and covers the period 1 March 1973 to 9 November 1973. The report was submitted by the author in November 1973.

The contractor's report number is LG73ER0153.

This technical report has been reviewed and is approved.

Rodney A Bartholomew

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Chief, Design Criteria Branch
Structures Division

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TABLE OF CONTENTS

ILLUSTRATIONS

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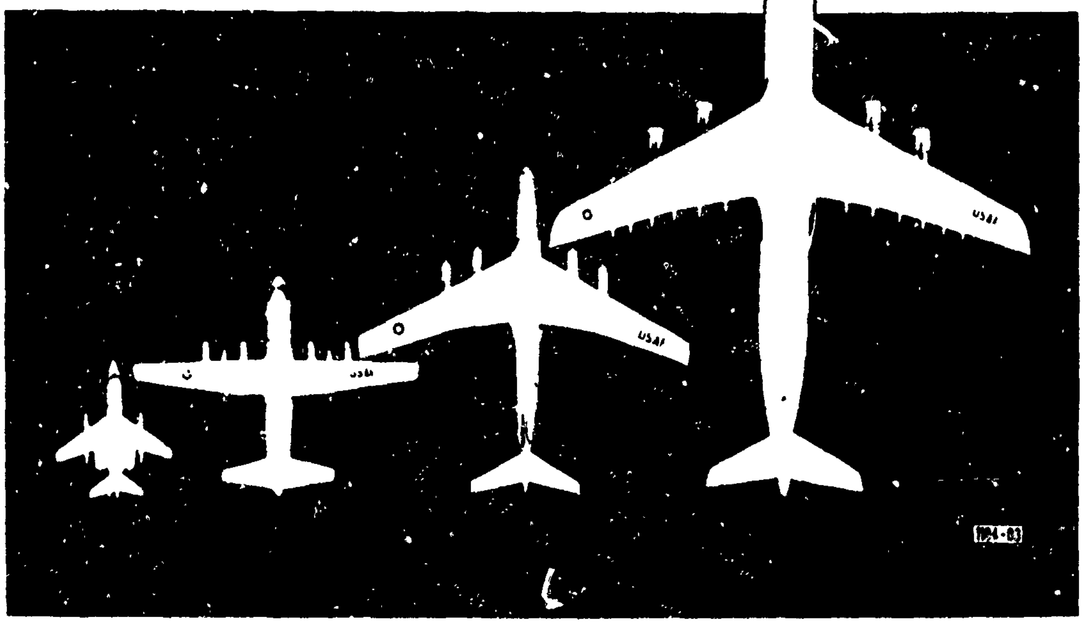
SYMBOLS

a, C_{L_α}	slope of lift curve
A	structural response quantity
b	turbulence intensity
c	reference chord
c.g.	center of gravity
g	gravitational constant
K_ϕ	spectral gust alleviation factor
K_o	zero crossing factor
L	turbulence scale
N, N_o	number of times per second load level x is crossed
P, P_1	proportion of time spent in turbulence
PSD	power spectral density
S	wing area
W, GW,	airplane weight
W.S.	wing station, inches from center line
X	response variable
X_L	limit load value
X_{1g}	1 g load level
μ	mass parameter $(2W/a\rho cS)$
ρ	air density
σ_w	r.m.s. vertical gust velocity
σ_x	r.m.s. value of variable x

AIRCRAFT SIZE COMPARISON



SECTION I

INTRODUCTION

Airplane design requirements for rough air encounter have been evolutionary. The trend has been to more complexity and sophistication of the analysis to develop design gust loadings. Advances in computer technology, flight testing, expanding data banks and the desire to better represent the flight environment have contributed to this trend. The analysis model has changed from a gust loads formula to transient time history, to continuous turbulence, and with all combinations of the above. Under contract with the Air Force Dynamics Laboratory, Lockheed-Georgia Company has performed the complete sequence of gust design procedures for the C-130, C-140, C-141A, and C-5A aircraft to provide validation of new gust design procedures.

Results are presented for the different successively detailed procedures of the design manual. Response data developed by use of the manual is compared to those from evaluation of analytical frequency response and/or flight test correlated data on an availability basis. Basic aerodynamic and loads data, mission profiles, and the turbulence parameters used to generate the results are included in this report. Precise agreement of the turbulence parameters P and σ with the final recommendations of Reference 2 for the exceedance analyses does not exist due to program concurrency. They are sufficiently close, however, so as not to alter any conclusions reached.

SECTION II

PROCEDURES AND BASIC DATA

The four aircraft used for validation of new gust design procedures are the Lockheed models C-130, C-140, C-141A, and C-5A. Basic geometrical description such as area, sweep, aerodynamic chords, taper, etc. are given on the respective three views, Figures 1, 2, 3, and 4.

The sequence of gust design procedures delineated in the design manual for vertical gust is followed and depicted on Figure 5. External loads are used with the assumption that they are representative of stress. Concurrent with this effort, Aeronautical Research Associates of Princeton provided updated parameters and changes in procedure. These changes are:

- Allowable X/A values for the preliminary design approach
- Check of the design for gust is at exceedance rate $N \leq 7.0 \times 10^{-8}$
- Load per g is used in Equation 34 in determining allowable gust intensity X/A
- Turbulence parameters P_1, P_2, σ_1, and σ_2 used to generate exceedance curves are presented in Figures 6 and 7. These parameters were further updated but would not change any of the conclusions of this evaluation.

Basic response data in terms of center of gravity acceleration and zero crossings are determined by use of the variations shown in Figures 8 and 9 as a function of the standard mass parameter. A constant value of scale of turbulence, L, equal to 750 is used for all altitudes. Mean square (r.m.s.) values of loads at any other point on the structure are determined by multiplying the r.m.s. center of gravity acceleration times the loads per acceleration at the desired location.

Fatigue analyses have been conducted for all of the study aircraft except the C-140. Design mission profiles are used for the C-141A and C-5A in this validation. Numerous missions have been defined for the C-130 series aircraft over the years. The mission profiles defined in 1969 to reflect C-130B and C-130E usage are the most representative of actual usage and are used for the C-130. Missions are defined for the C-140 consistent with its usage. Various levels of detail are present in the design missions in terms of mission segments. Consistent with the design manual,

each mission is condensed to six segments as shown in Figure 10. Nine missions are used for the C-130, eight missions are used for the C-141A, six missions are used for the C-140, and 15 missions are used for the C-5A aircraft. Time, altitude, speed, and weight are the operational parameters used to describe each mission.

The sequence of gust design includes four methods: preliminary, detailed, comparison, and load exceedance. The criteria for the preliminary design are shown in Figure 11. If the X/A for the flight condition selected is to the right of the curve, the design is judged to be safe. It is required that all possible flight conditions be enveloped. Maximum speeds considered for this method are the placard maximum level flight speeds. The X/A value is defined as

$$\frac{X}{A} = \frac{\frac{X_L}{X_{1g}} - 1}{1.1A_R}$$

where

X_L is limit load

X_{1g} is the initial steady one g flight load

A_R is the unit response load.

The composite approach based on cg acceleration is an extension of the preliminary design approach which does not require the use of the loads at 1.0g but rather the maneuver design load factor. The design chart for this approach is presented in Figure 12.

Detailed design is characterized by establishment of missions instead of flight envelope conditions of the preliminary design approach. Response data A is determined in an identical manner as that used in the preliminary design approach. The design is judged to be safe if the exceedance rate $N \leqq 7.0 \times 10^{-8}$. Evaluation of the airframe frequency response can also be used to determine response load data.

It is usually desirable to know how a new design compares in gust loadings with past aircraft that have proven themselves by years of safe operation. Figure 13 provides the format for this evaluation.

Load exceedance design is very similar to the detail analysis. The detail and the exceedance approach result in identical loads at the design exceedance rate. The total exceedance curve is developed by the addition of two logarithmic functions of e^{-at} type. The detailed design approach operates on the function which contributes practically all of the loadings at the design load levels. The other function is of primary interest in fatigue evaluations. The exceedance design is also used in this report to define a total loads spectra or exceedance curve based on mission utilization. The primary difference in the detailed and exceedance design method is one of format and data presentation. Individual mission check or total load exceedance check is made at an exceedance rate $N \lessapprox 7.0 \times 10^{-8}$.

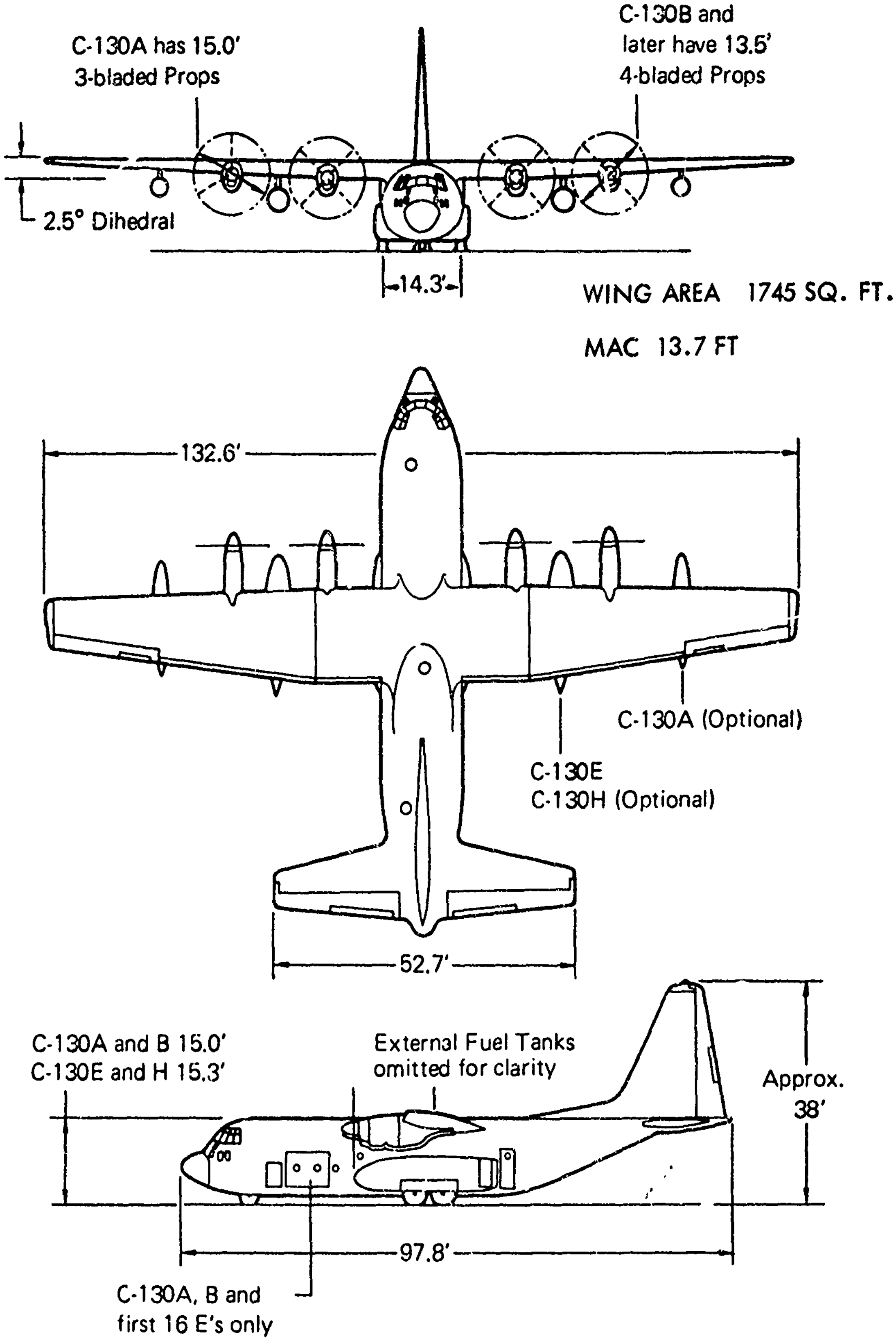


Figure 1 General Arrangement, C-130

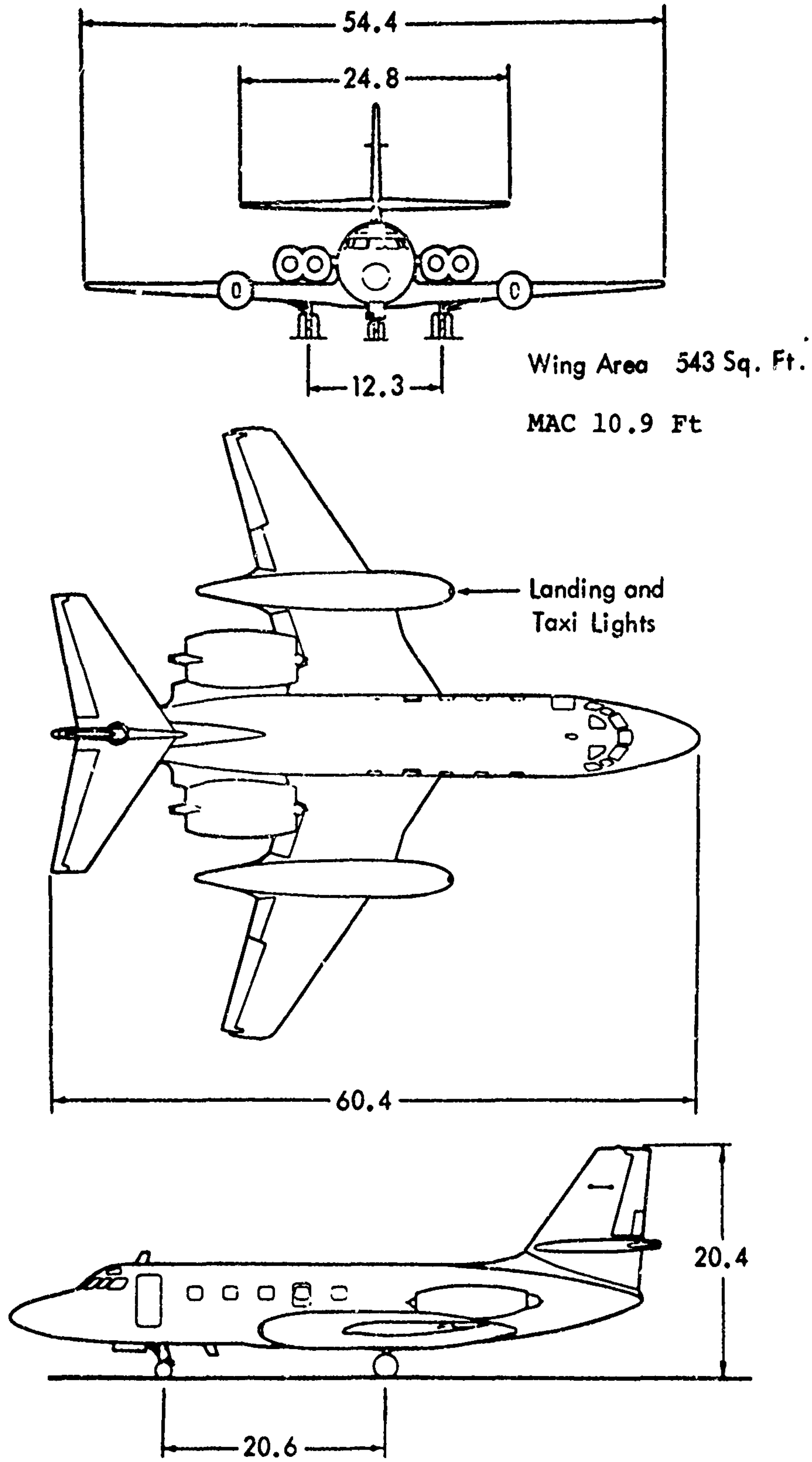


Figure 2 General Arrangement, C-140

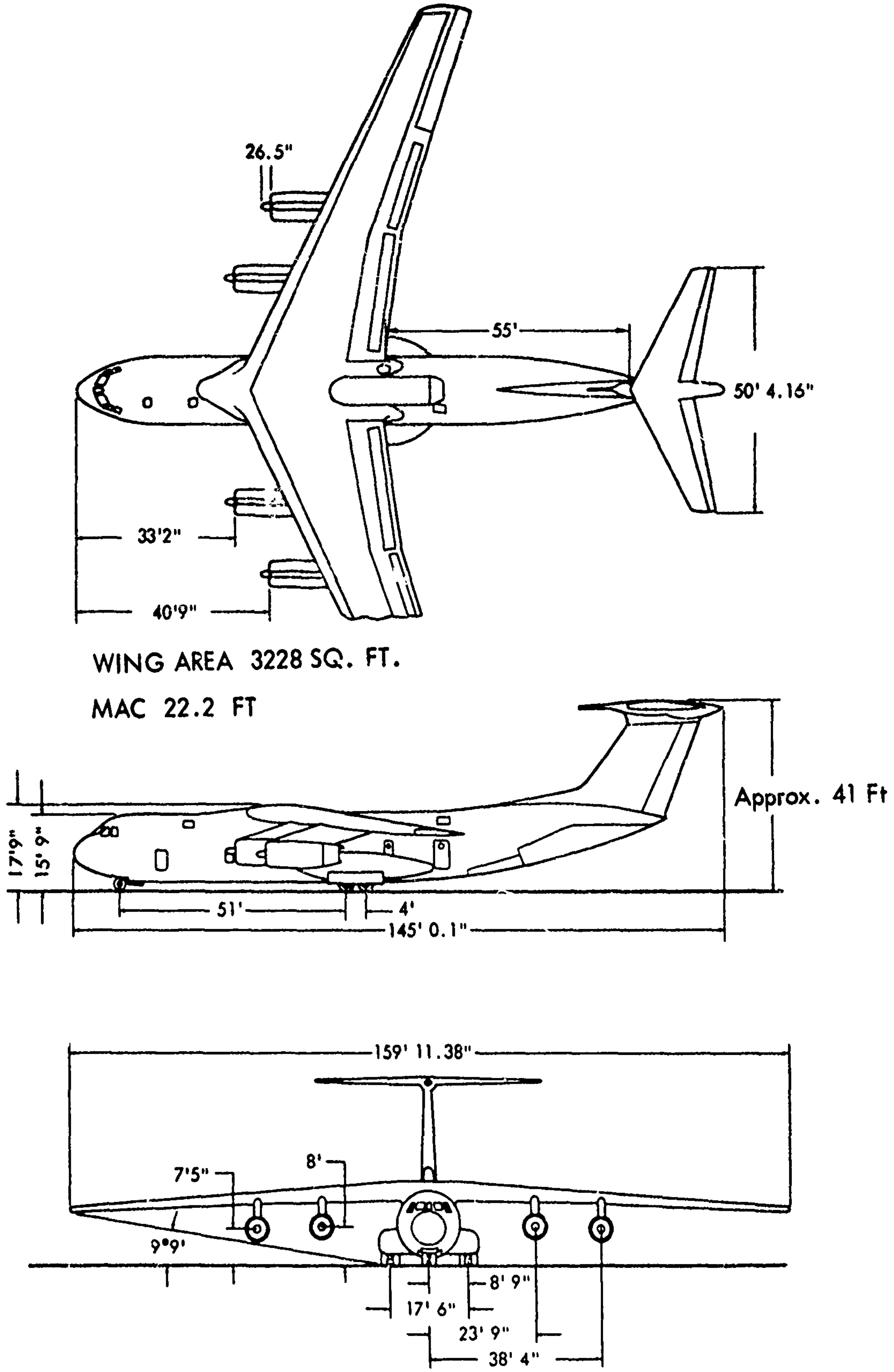


Figure 3 General Arrangement, C-141A

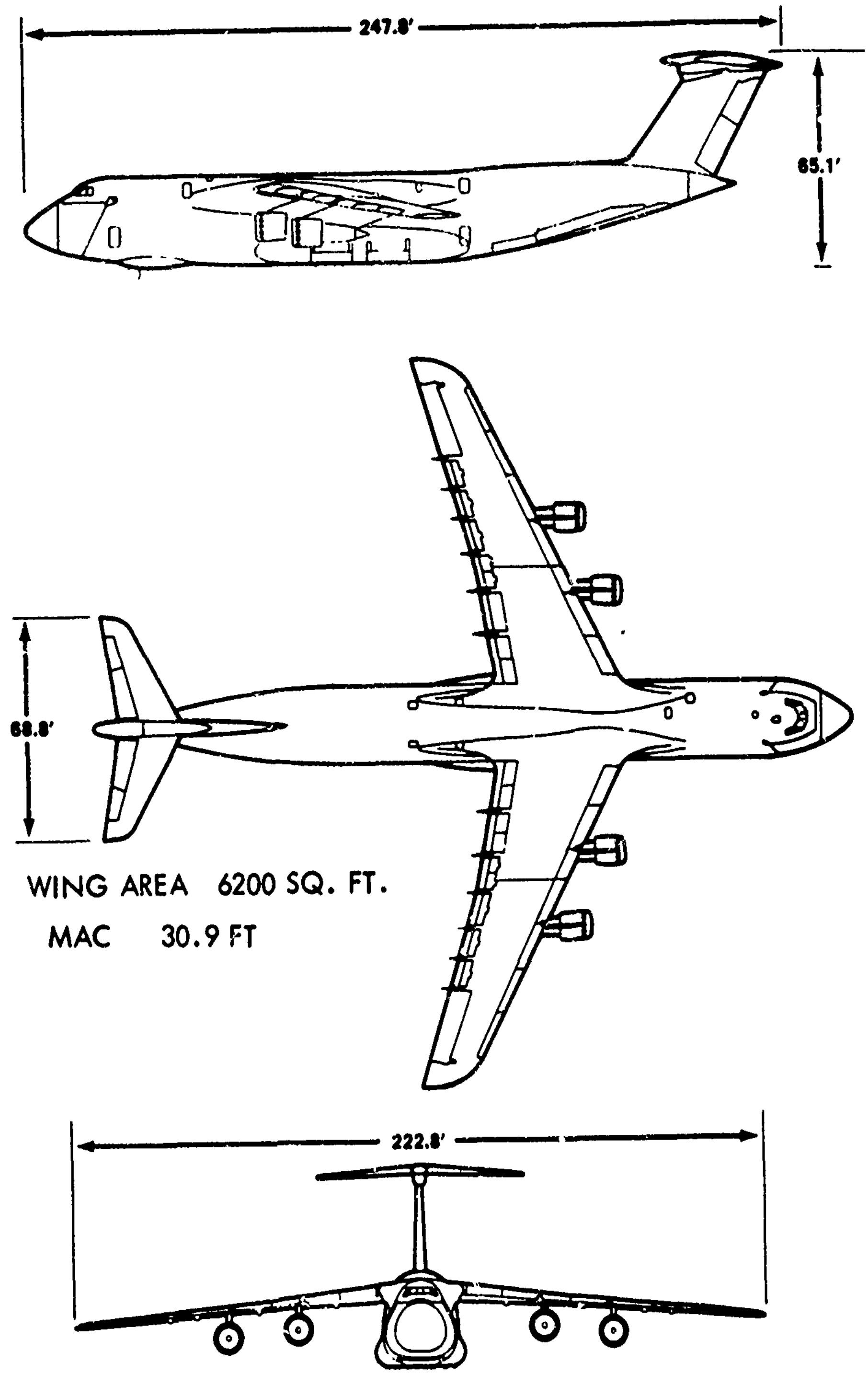


Figure 4 General Arrangement, C-5A

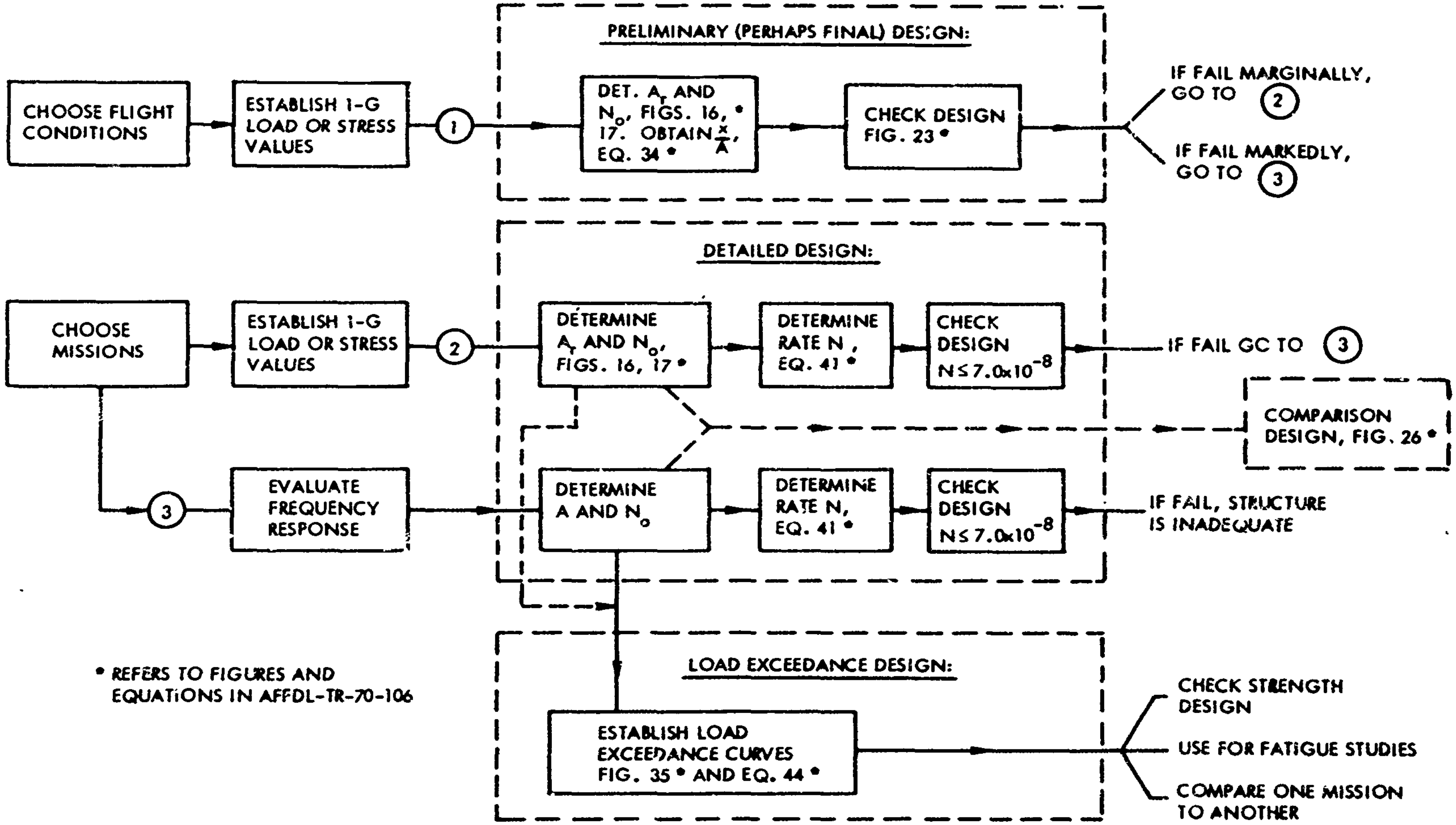


Figure 5 Sequence of Gust Design Procedures

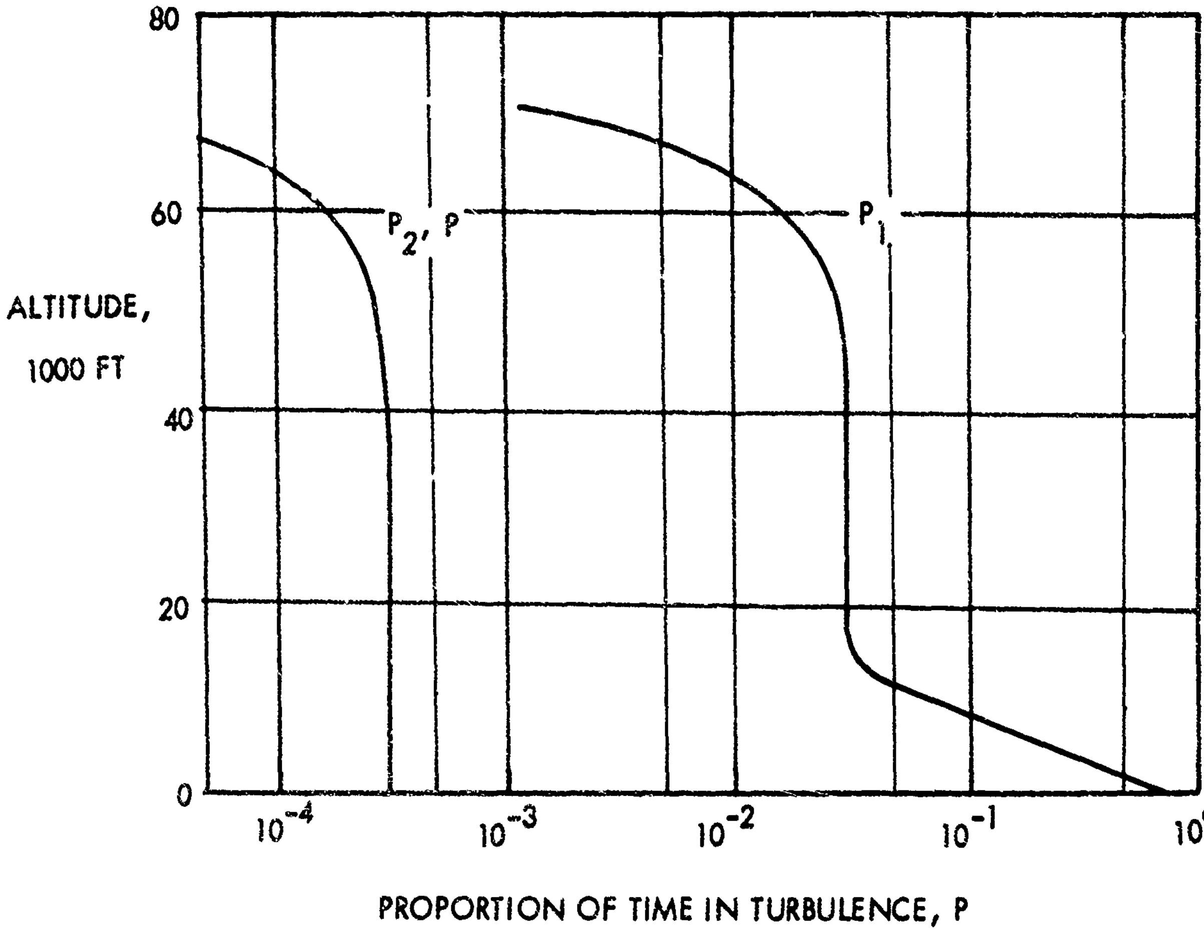


Figure 6 Turbulance Parameters

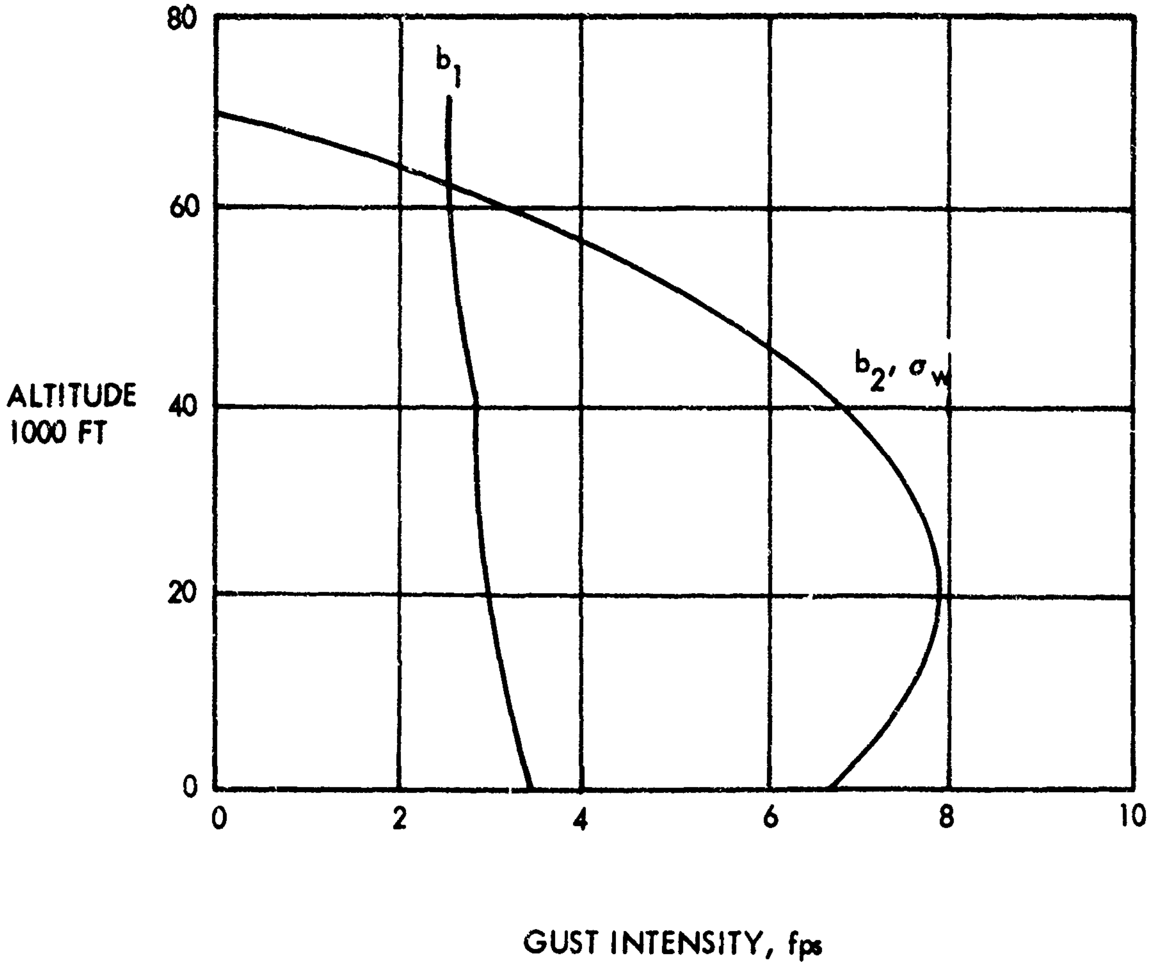


Figure 7 Gust Intensity

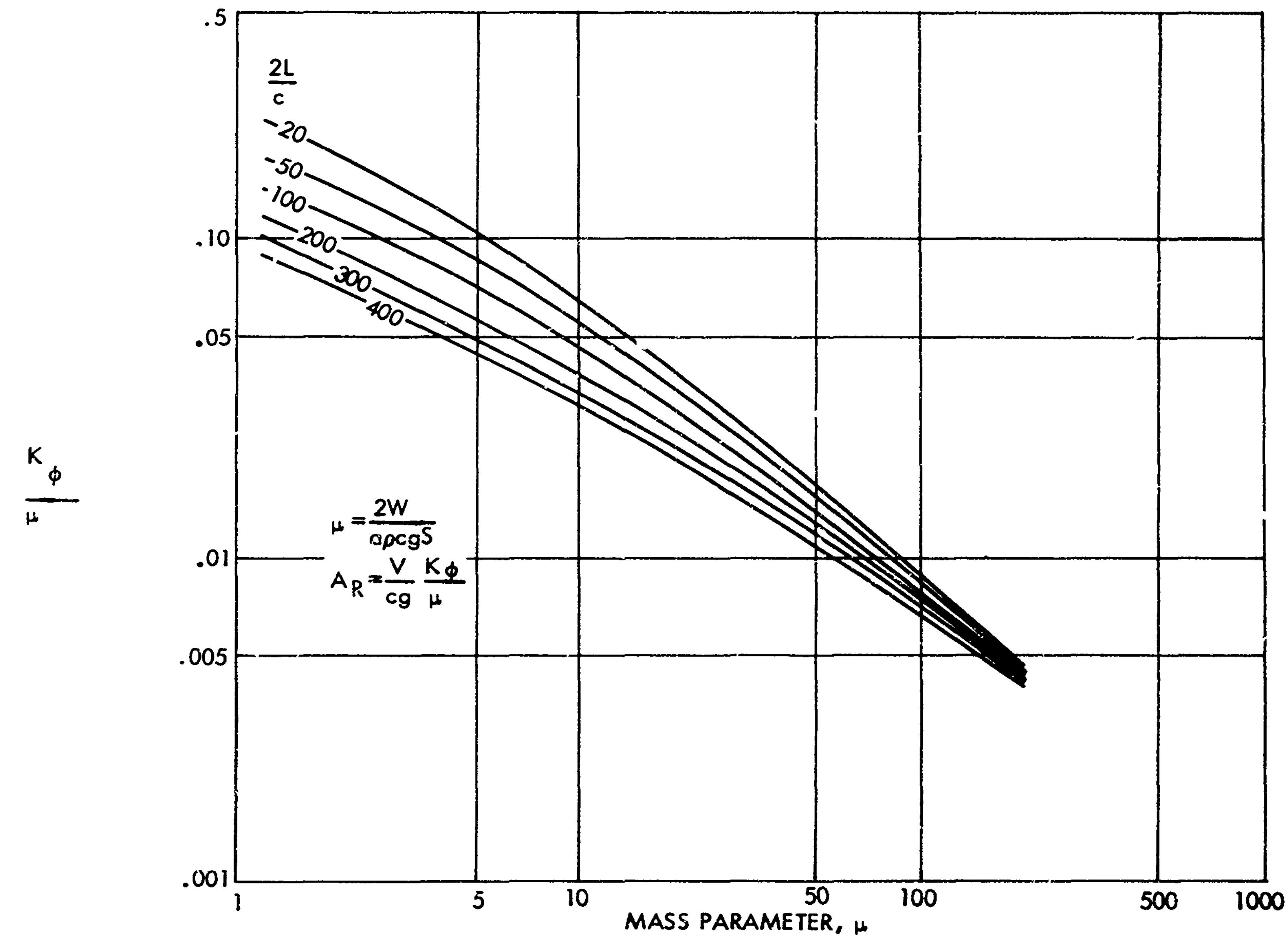


Figure 8 Variation of $\frac{K_\phi}{\mu}$ With μ

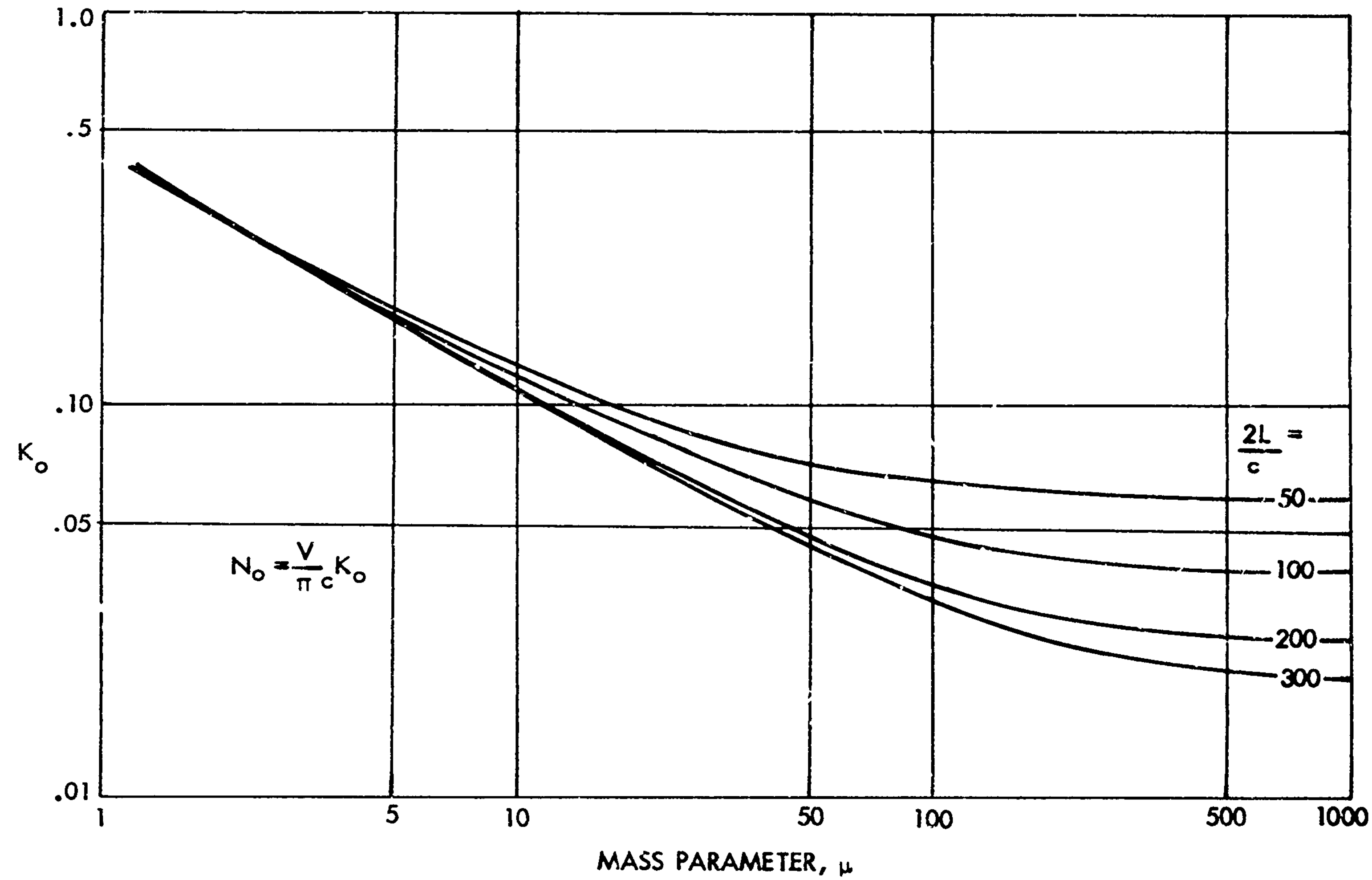


Figure 9 Zero-Crossing Values K_o

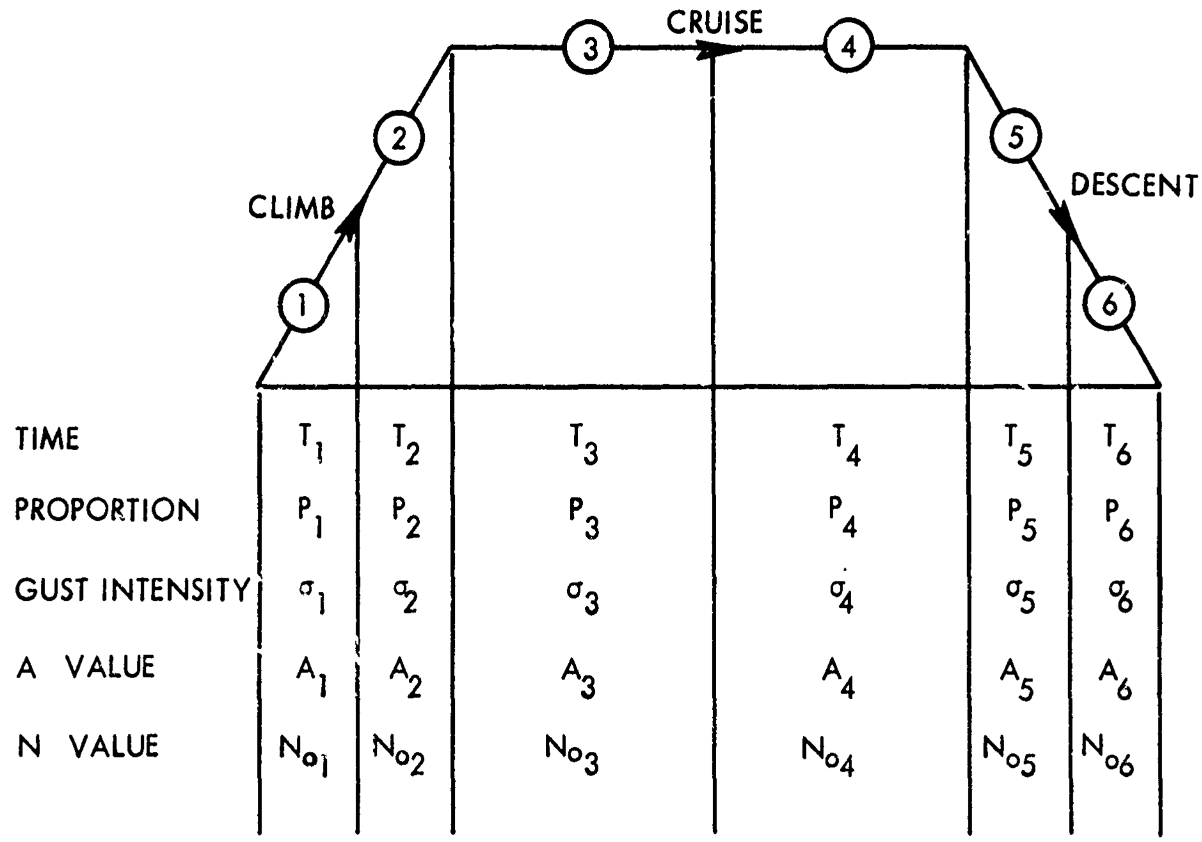


Figure 10 Illustrative Mission Profile

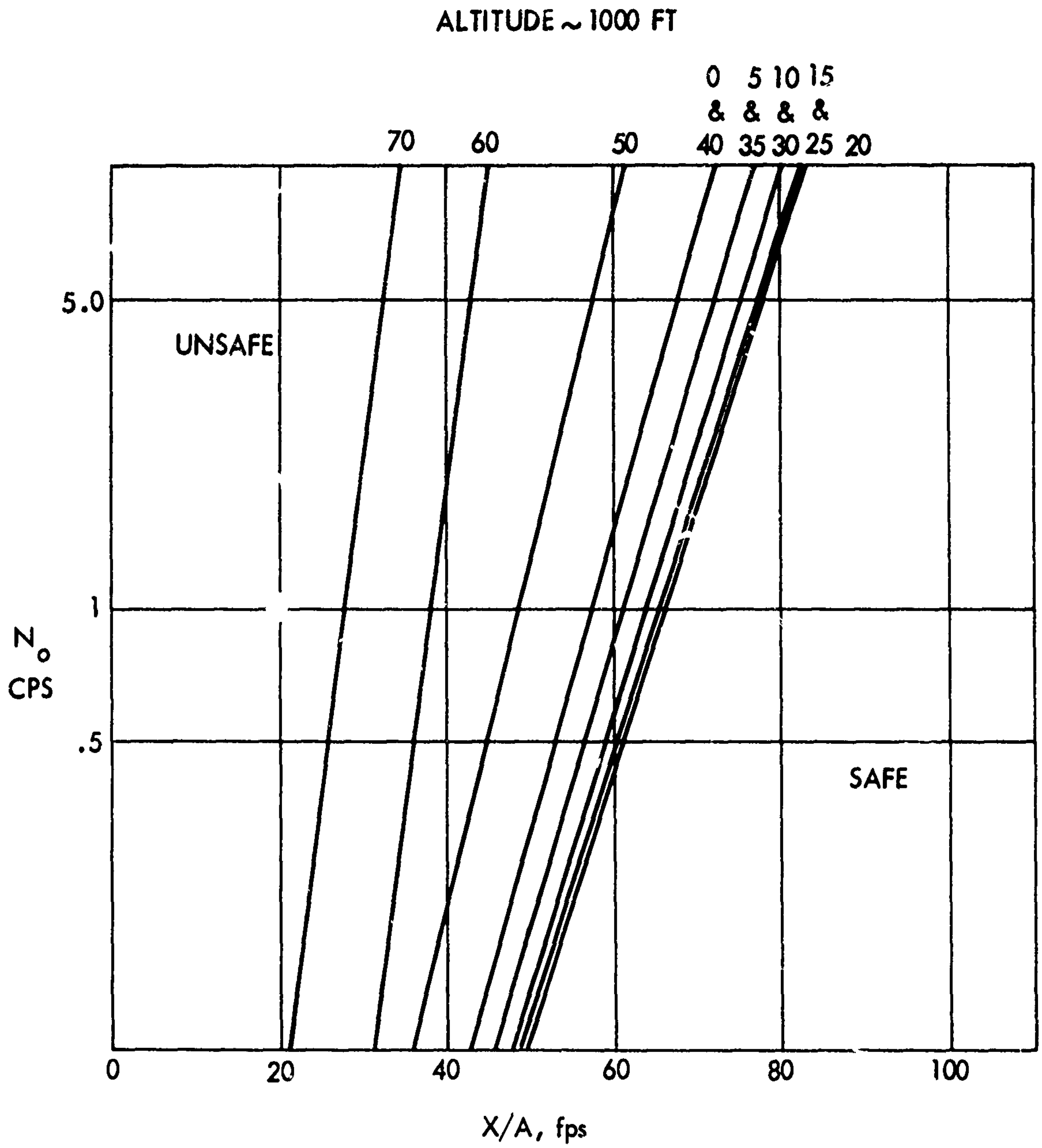


Figure 11 Preliminary (Perhaps Final) Criteria

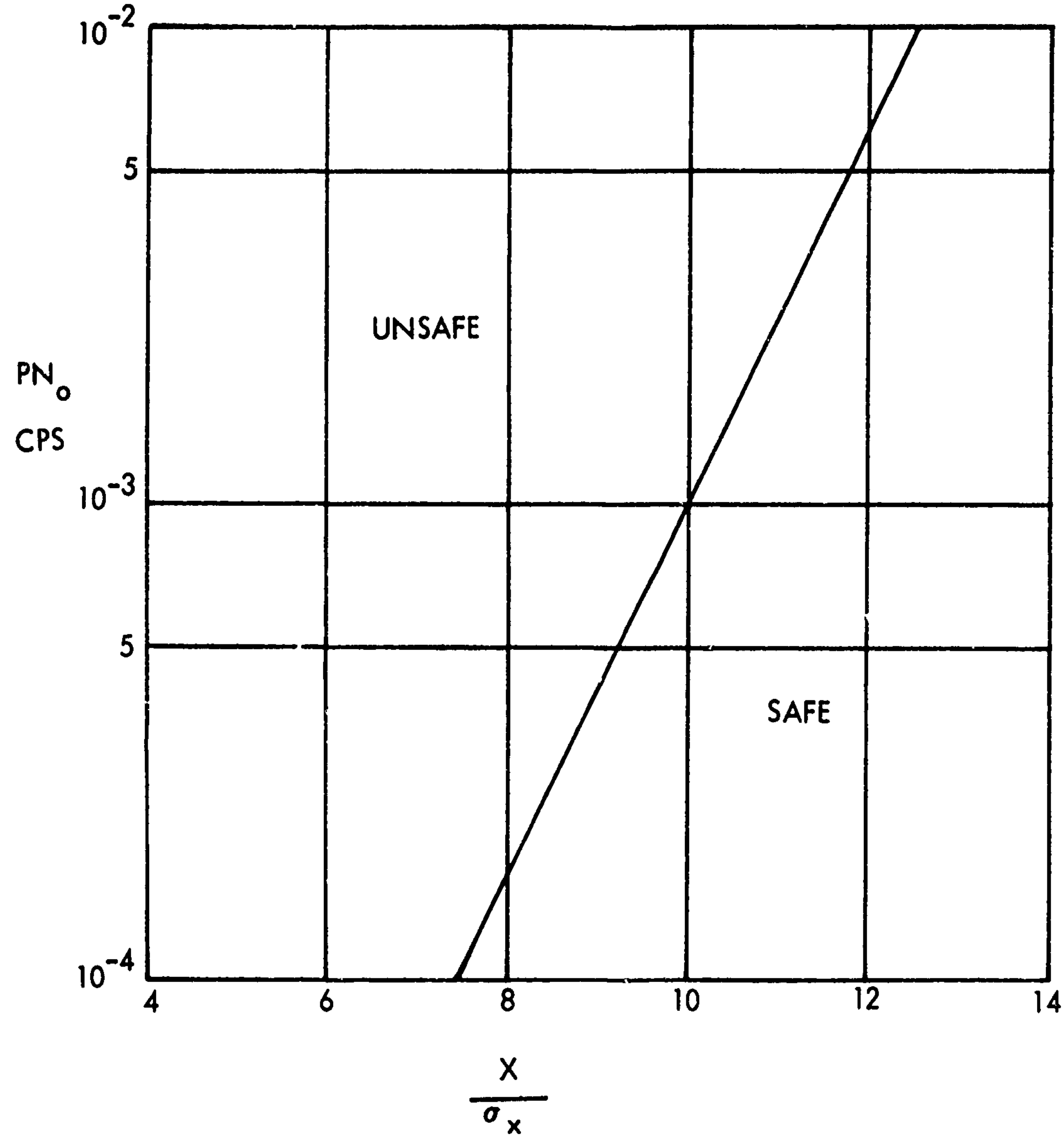


Figure 12 Design Chart Using Composite Values of σ_x and PN_o Criteria

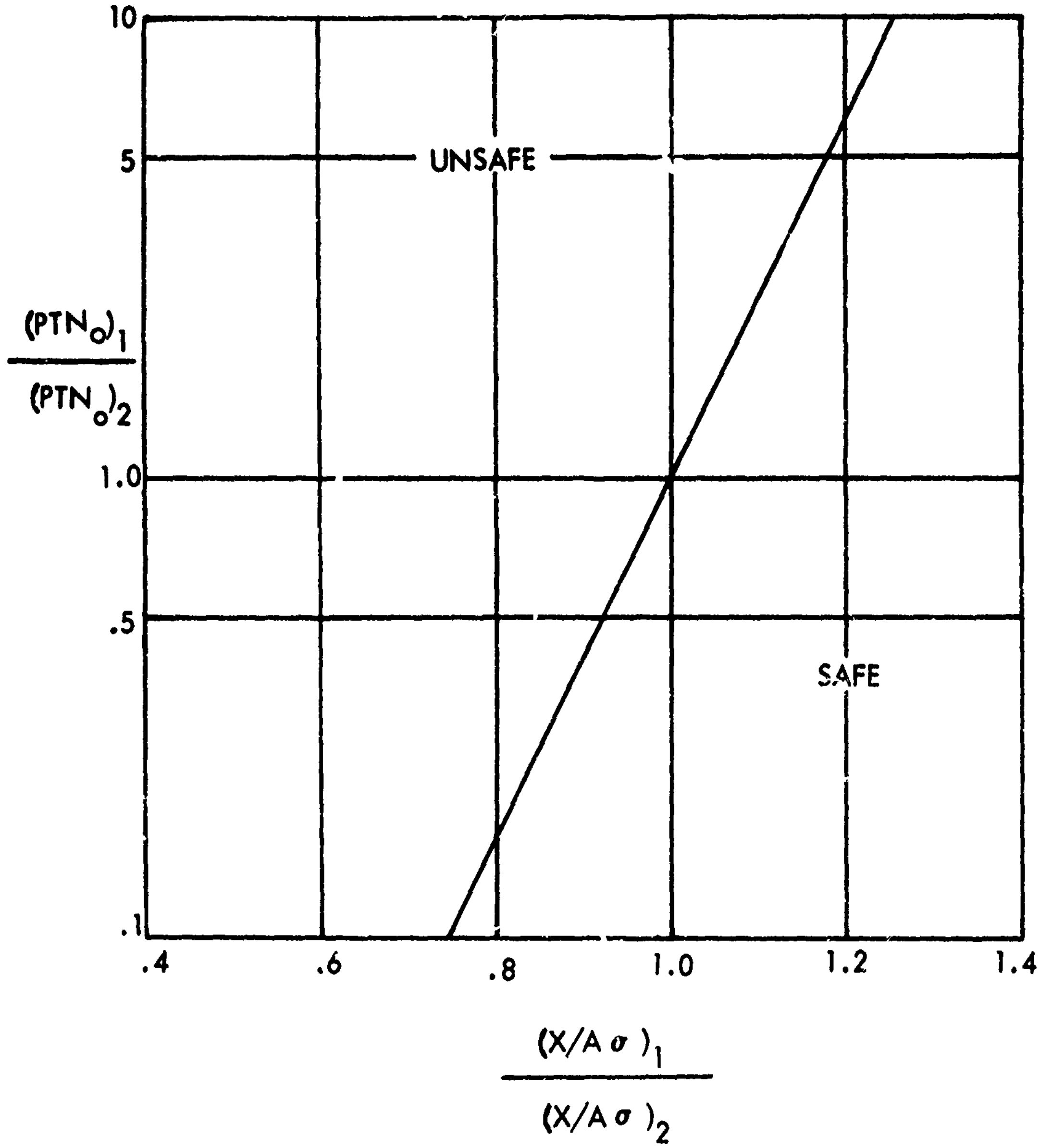


Figure 13 Design by Comparison Summary

SECTION III

RESULTS SUMMARY

Comparative results for the study aircraft for each of the design approaches are presented in the next five figures. Detailed data by aircraft are presented in separate sections of this report.

Preliminary (Perhaps Final)

Results from the Preliminary (perhaps final) Design Summary for altitudes of 1,000 feet and 20,000 feet are shown on Figure 14 and 15, respectively. All aircraft resulted in safe gust design at altitudes above 20,000 feet. The results are for the most critical flight values for each aircrafts operational envelope. Three C-130 values are shown because this aircraft has three flight operational envelopes depending upon mission requirements. Both the nominal 35,000 and 45,000 payload missions indicate a need for load increase or a change in the operational flight envelope in terms of a speed placard below 20,000 feet.

Composite Approach Based on c.g. Acceleration

The composite approach is not a basic design method but, according to the manual, is to serve as a check as to whether more detailed treatment is necessary. The C-130, C-141A, and the C-5A showed missions that are unsafe even though the C-141A and the C-5A showed safe load levels for gust in the preliminary design method. The apparent paradox is due to the fact that the composite check as directed in the manual is based upon acceleration and the preliminary evaluation uses the ratio of limit to one g load. The load ratio can and is significantly greater than the increment of 1.5. For example, it is not uncommon that the 1.0g level be different by a factor of 2.0 from zero to maximum design cargo. The limit load does not vary but the minimum incremental ratio at the highest load level is 1.5. Therefore, an incremental ratio of 3.0 is possible and probable. The composite approach based on c.g. acceleration is found to be of little value when applied to cargo transports.

Design by Comparison

Design acceptability by comparison is illustrated on Figure 17. Comparisons are made for both c.g. acceleration and wing bending moment using the C-130 as the baseline

to which the other study aircraft are compared. The C-130 was selected because of its longevity and gust criticalness in the preliminary evaluation. The four aircraft compared in this manner result in safe designs.

Load Exceedance Design

The design exceedance rate is taken as the check design value of 7.0×10^{-8}. Exceedance curves for each aircraft in terms of percent limit design load are presented on Figure 18. The curves generally reflect the trend to higher wing loadings and mass parameters for the newer and larger aircraft. The C-130, for the same exceedance rate, results in significantly higher loadings in percent limit design load. These loads are for wing root bending moment and are for the design mission profiles and utilization excluding contour flying turbulence.

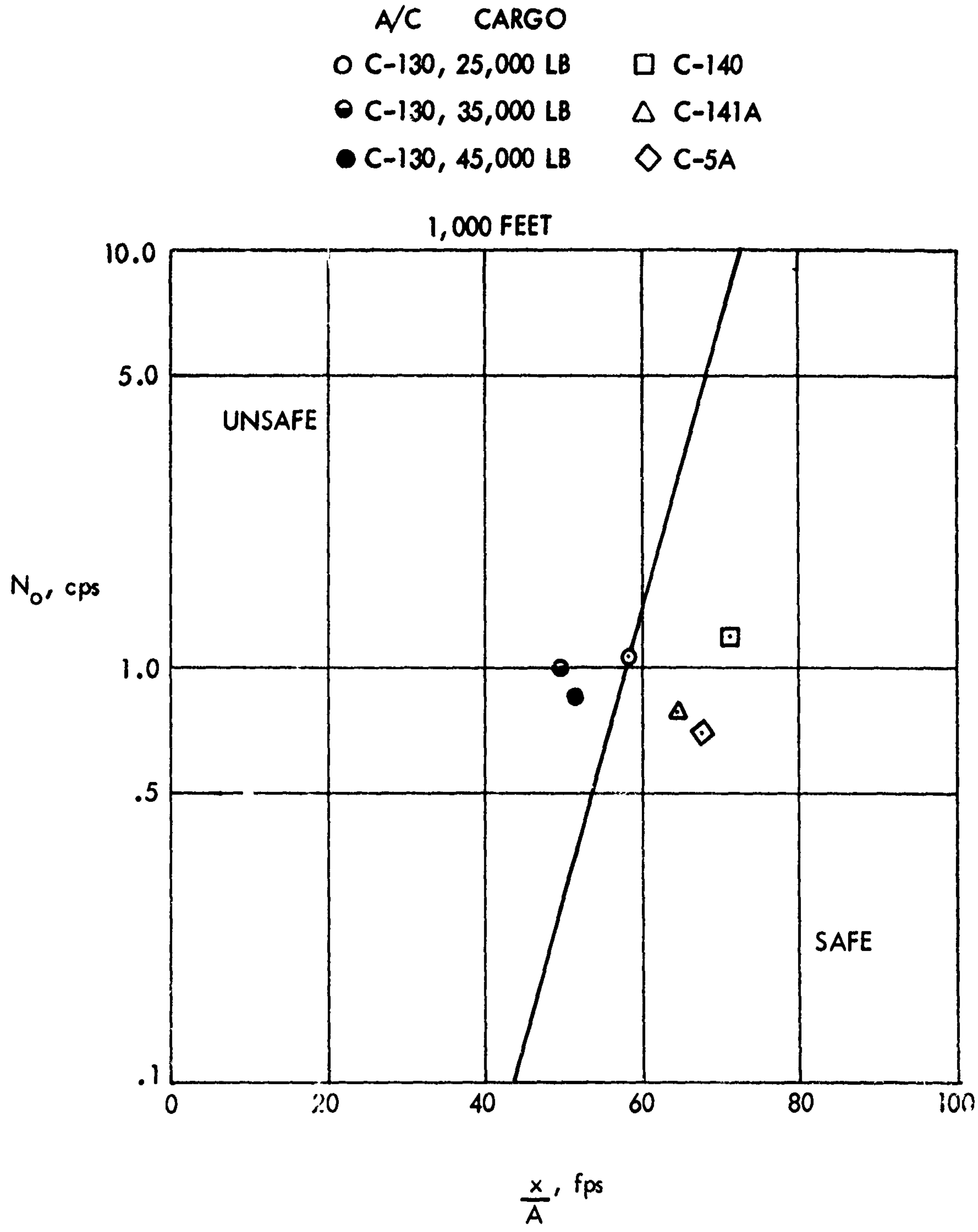


Figure 14 Preliminary (Perhaps Final) Design Summary, 1000 FT.

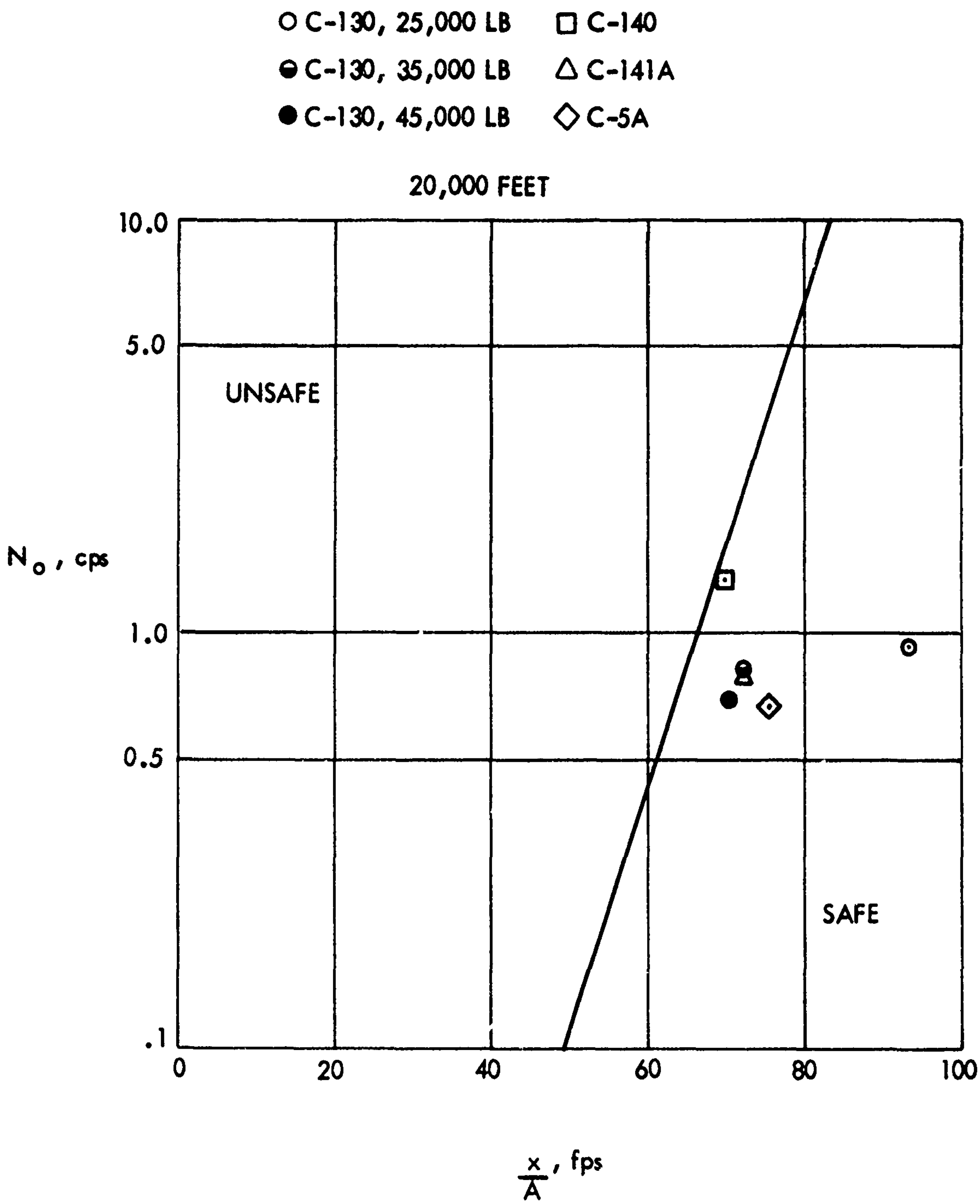


Figure 15 Preliminary (Perhaps Final) Design Summary, 20,000 Feet

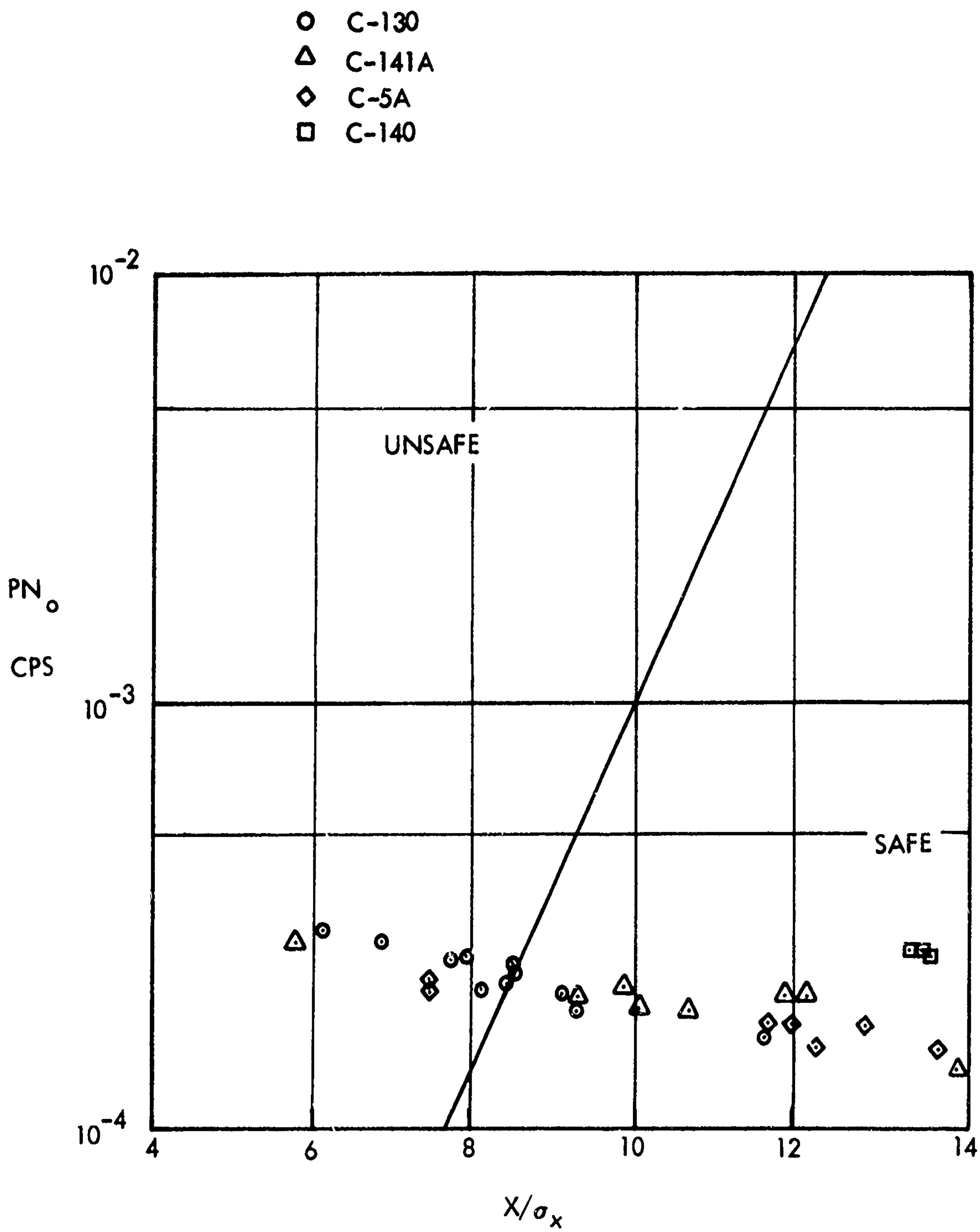


Figure 16 Composite Design Summary

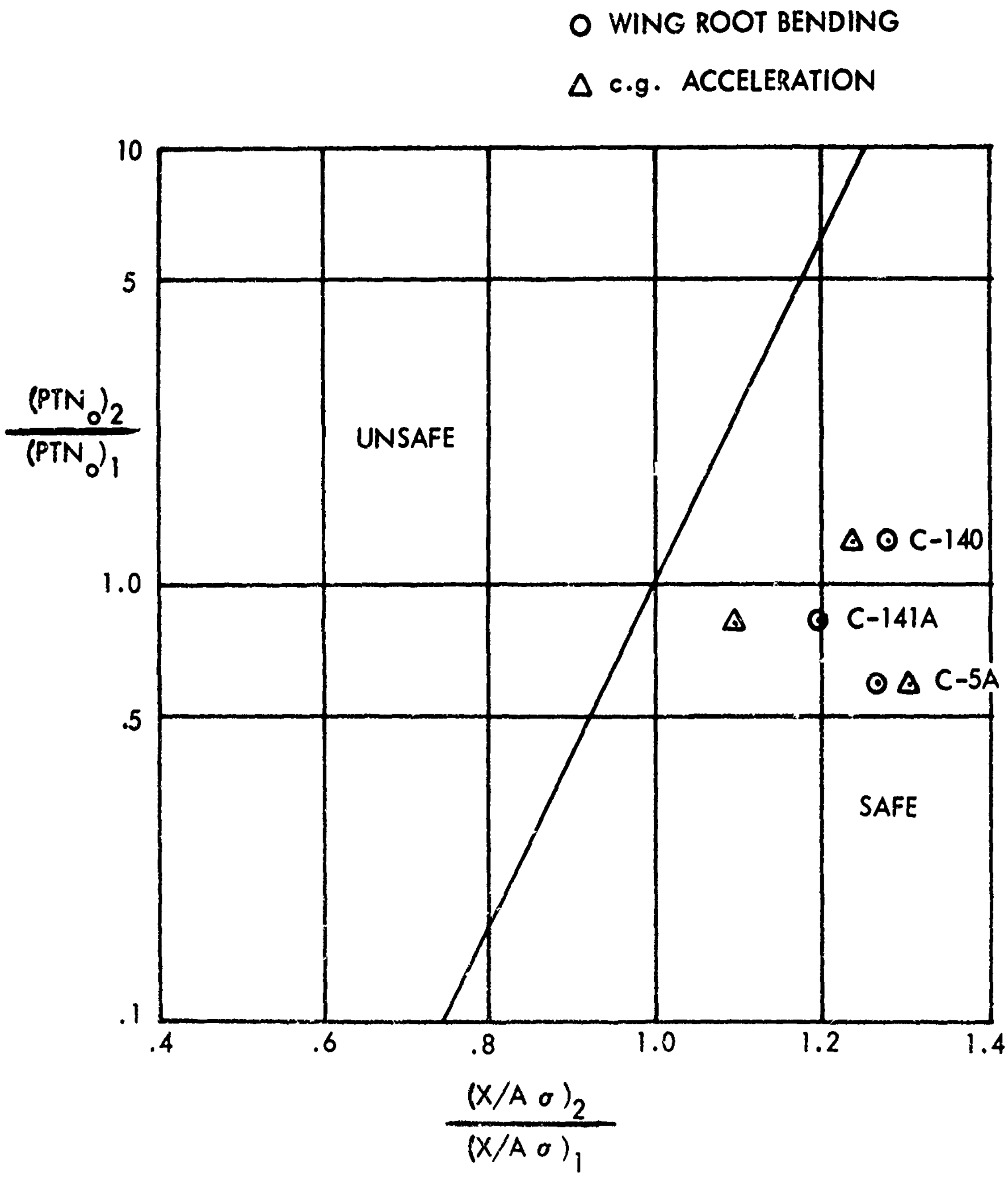


Figure 17 Design by Comparison Summary

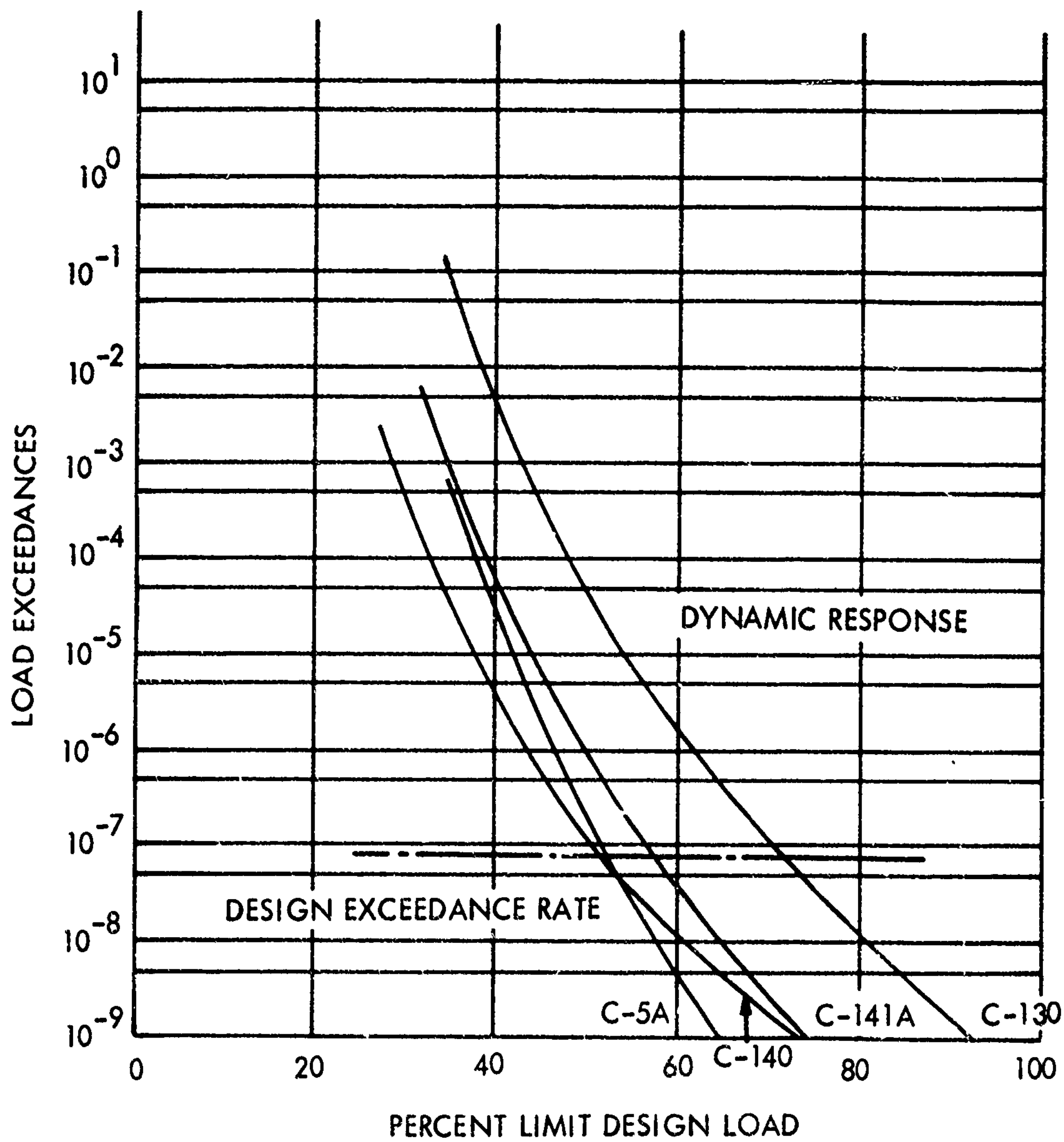


Figure 18 Load Exceedance Design Summary

SECTION IV

C-141A ANALYSIS RESULTS

Basic Data

The design and substantiated operational flight envelope for the C-141A is given on Figure 19 in terms of limit speed altitude schedule and allowable cargo and fuel weight combinations. The C-141A is a transport designed for symmetric maneuvering load factors of +2.5 and -1.0. The design gust criteria were the gust loads formula of MIL-A-8861 and a transient 1-cos discrete gust analysis with a dynamic accountability factor (DAF) as substantiated by a miles to exceed mission analysis based on power spectral techniques. The missions used in the design are given in Figure 20. These missions were derived from fatigue requirements. Substantially more segments were used in the original design and were reduced to six segments as directed by the design manual. Mission 1 is training, Missions 2 and 3 are the logistics missions and are the basic intended usages, Missions 4, 5, 6, and 7 are various airdrop and low level missions, and Mission 8 reflects flight test and other miscellaneous items. Design mission utilization is included for each mission type.

In addition to the operational envelope, missions and turbulence parameters; lift curve slope is required to determine the single degree of freedom center of gravity response. The airplane elastic lift curve slope for minimum reserve fuel and maximum payload as a function of altitude and Mach is given on Figure 21. Gust response at any desired locations is by unit load per center of gravity response. The unit load per response from maneuvers is used to determine the loading due to the gust increment. One g flight loads are used to determine net loads and allowable incremental loads for any chosen flight condition. Lines of constant gross weight are included. Maximum unit loads occur for maximum cargo and gross weight for both the wing root (W.S. 77.7) and mid-span (W.S. 460).

Preliminary (Perhaps Final)

Inspection of the single degree of freedom response and equation for center of gravity response shows that the minimum flying weight and the highest speed produce the maximum acceleration response. Maximum wing root unit loads occurred for maximum cargo and are essentially constant with increasing gross weight. Maximum gust

response occurs at the minimum flight weight for any defined cargo. Therefore, maximum cargo and minimum reserve fuel is expected to produce gust critical loadings. Figure 24 presents a design weight comparison and, as deduced above, the maximum cargo and minimum structural reserve fuel weight result in minimum safety margins. Decreasing cargo adds safety margins as does the addition of fuel at maximum cargo. All data points are for the placard speed of 350 KEAS. The complete results for the preliminary design approach are presented in Figure 25 for envelope conditions. The higher altitudes are less critical due to the fact that the design airspeed decreases faster than the allowable value of X/A. Mid span is less gust critical than the wing root as shown in Figure 26.

Part of the preliminary design approach is a composite center of gravity acceleration or load factor evaluation. Basic logistics and training missions (1, 2, & 3) result in a safe evaluation. Mission 4 indicates unsafe. This mission is a lightweight, high-speed mission, and the evaluation is based on acceleration. To be consistent with the preliminary design approach, it would be better to use load. Figure 32 can be used to illustrate this conclusion. Mission 5 has the highest load exceedance rate with Mission 4 being orders of magnitude less severe. Mission 5 is maximum cargo and Mission 4 is roughly 30 percent of the maximum cargo weight.

Detailed Design Approach

Detailed design, if required, uses the design missions and requires that a minimum mission exceedance rate, N, of 7.0×10^{-8} exist. The mission rate can be evaluated using one degree of freedom response results or using results from a frequency response evaluation which includes significant structural modes. Gust response at the center of gravity for the single degree of freedom system presented in the design manual is compared to the values currently used on the C-141A fatigue monitoring program. These data are part of the C-141A data bank and are correlated to flight test results from the dynamic response tests. Bending moment response is compared on Figure 29. Zero crossing or characteristic frequency of the system is compared on Figure 30. The design manual single degree of freedom method provides a good approximation of the C-141A basic gust response.

The complete spectrum of results from the detailed analysis for the C-141A is presented on Figure 31. Exceedance rate to reach limit load for both the one degree of freedom and dynamic response is shown for each mission. All values above the line indicate that the dynamic response is more critical than the one degree of freedom method. In general, the mid-span wing station indicates structural response effects. Data clustering near the line indicate either method will result in similar loadings due to gust. These exceedance rates do not reflect any mission utilization factors.

Exceedance curves for the eight missions are depicted on Figure 32. The point where the mission curve intersects the limit design load value is the data plotted on Figure 31. The total effective mission values are developed by use of the stated mission utilization and addition of the exceedances at a given load level. This total load exceedance curve converted to percent design limit load is presented on Figure 33. Figure 34 is a comparison of loads using the one degree of freedom and the dynamic response data. Essentially identical loads result for the C-141A.

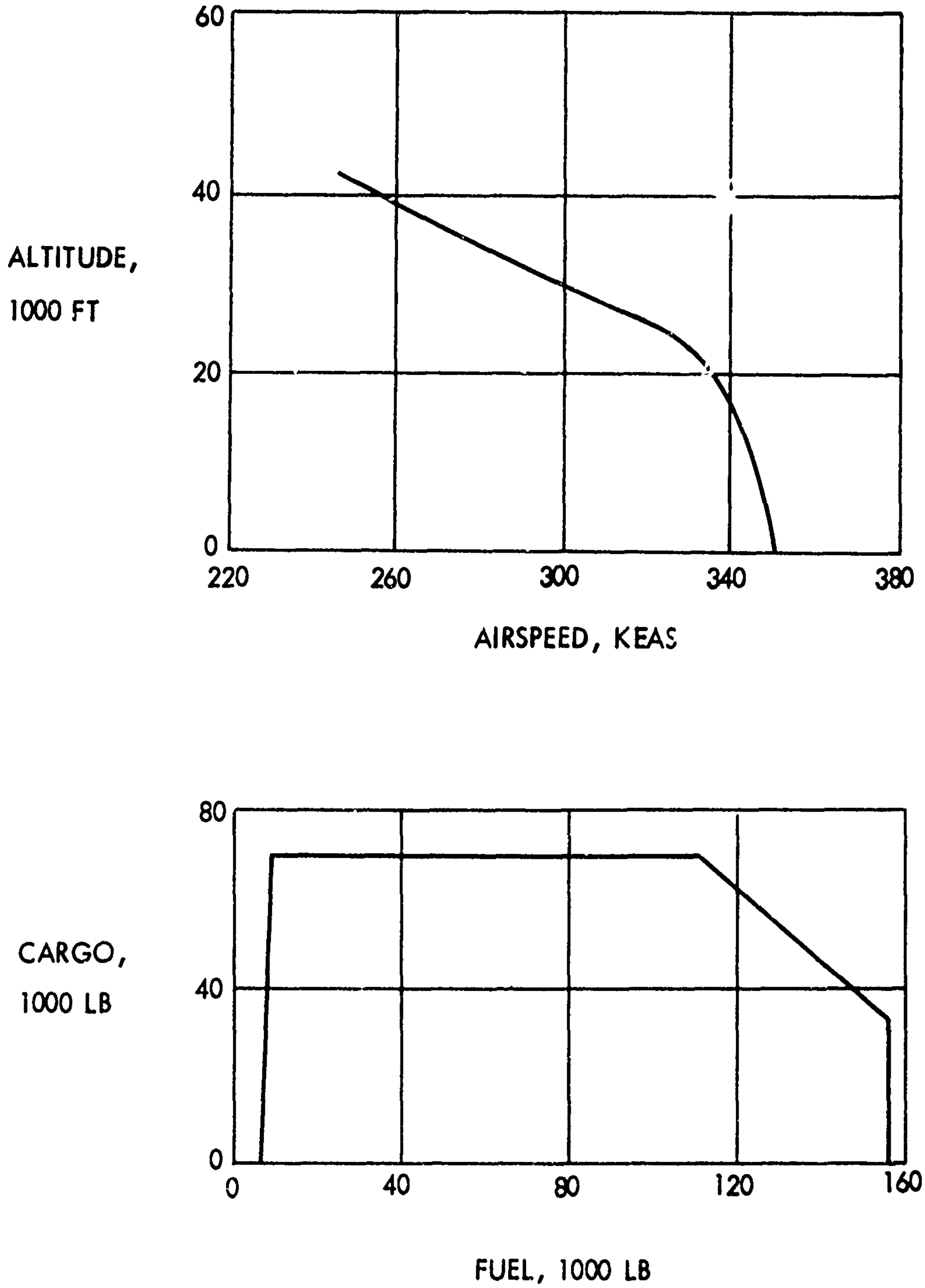


Figure 19 Operational Flight Envelope, C-141A

C-141A MISSION 1

SEGMENT	1	2	3	4	5	6	
TIME	14	101	6	124	10	13	MINUTES
ALTITUDE	17000	34000	18000	1000	1000	1000	FEET
SPEED	277	193	265	135	310	140	KEAS
GROSS WT	236000	226000	218000	199000	197000	176000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.23

C-141A MISSION 2

SEGMENT	1	2	3	4	5	6	
TIME	15	112	113	113	112	6	MINUTES
ALTITUDE	16000	36000	36000	36000	36000	21000	FEET
SPEED	287	240	240	240	240	257	KEAS
GROSS WT	295000	282000	261000	241000	220000	207000	POUNDS
CARGO WT	56770	76770	56770	56770	56770	56770	POUNDS

UTILIZATION - 0.52

C-141A MISSION 3

SEGMENT	1	2	3	4	5	6	
TIME	19	224	224	224	6	5	MINUTES
ALTITUDE	16000	36000	36000	36000	21000	1000	FEET
SPEED	293	240	240	240	305	152	KEAS
GROSS WT	312000	287000	245000	202000	181000	180000	POUNDS
CARGO WT	40000	40000	40000	40000	40000	40000	POUNDS

UTILIZATION - 0.18

C-141A MISSION 4

SEGMENT	1	2	3	4	5	6	
TIME	5	44	5	75	50	5	MINUTES
ALTITUDE	10000	21000	11000	1000	21000	1000	FEET
SPEED	289	338	347	350	338	140	KEAS
GROSS WT	229000	220000	212000	200000	152000	143000	POUNDS
CARGO WT	25000	25000	25000	25000	0	0	POUNDS

UTILIZATION - 0.009

Figure 20 Design Mission Profiles, C-141A

C-141A MISSION 5

SEGMENT	1	2	3	4	5	6	
TIME	17	121	157	11	152	5	MINUTES
ALTITUDE	14000	29000	1000	20000	39000	21000	FEET
SPEED	245	294	350	260	159	277	KEAS
GROSS WT	312000	297000	274000	168000	158000	150000	POUNDS
CARGO WT	70000	70000	70000	0	0	0	POUNDS

UTILIZATION - 0.0045

C-141A MISSION 6

SEGMENT	1	2	3	4	5	6	
TIME	15	175	22	180	187	5	MINUTES
ALTITUDE	14000	30000	18000	1000	38000	20000	FEET
SPEED	298	220	280	350	170	310	KEAS
GROSS WT	312000	292000	275000	261000	150000	146000	POUNDS
CARGO WT	50000	50000	50000	50000	0	0	POUNDS

UTILIZATION - 0.0045

C-141A MISSION 7

SEGMENT	1	2	3	4	5	6	
TIME	16	210	120	180	30	66	MINUTES
ALTITUDE	14000	30000	15000	1000	1000	25000	FEET
SPEED	298	220	328	350	350	164	KEAS
GROSS WT	312000	289000	268000	241000	158000	148000	POUNDS
CARGO WT	50000	50000	50000	50000	0	0	POUNDS

UTILIZATION - 0.0045

C-141A MISSION 8

SEGMENT	1	2	3	4	5	6	
TIME	17	75	45	24	79	7	MINUTES
ALTITUDE	16000	34000	1000	20000	40000	22000	FEET
SPEED	289	250	350	266	212	282	KEAS
GROSS WT	285000	268000	246000	220000	177000	167000	POUNDS
CARGO WT	45000	45000	45000	45000	0	0	POUNDS

UTILIZATION - 0.0485

Figure 20 Design Mission Profiles, C-141A (Continued)

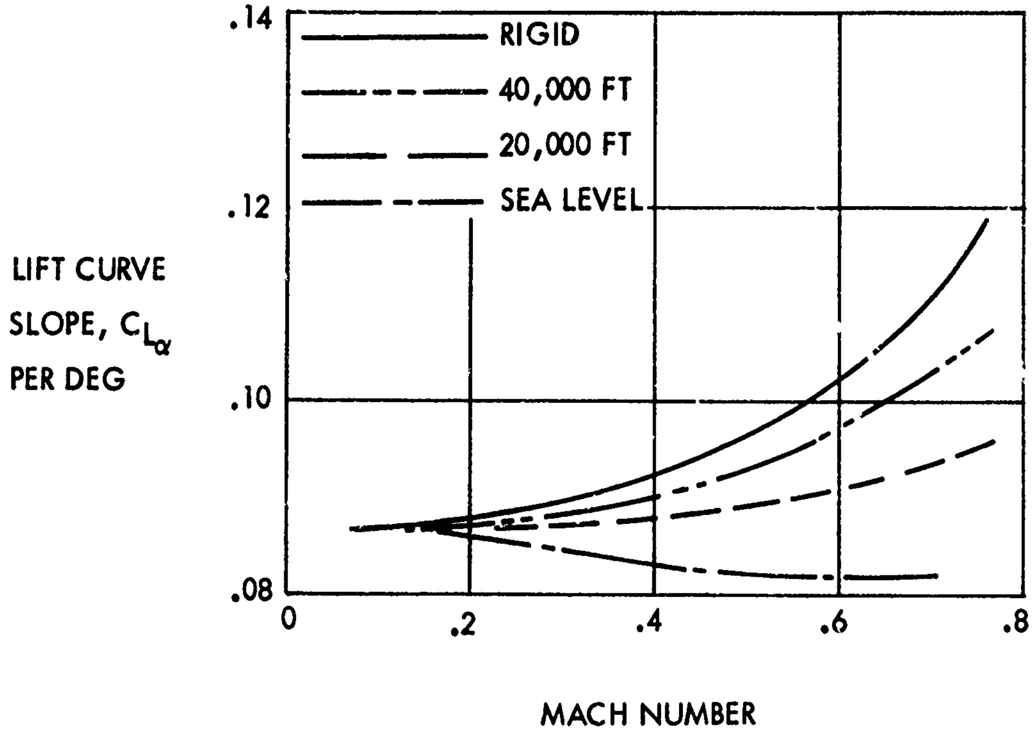


Figure 21 Elastic Lift Curve Slope, C-141A

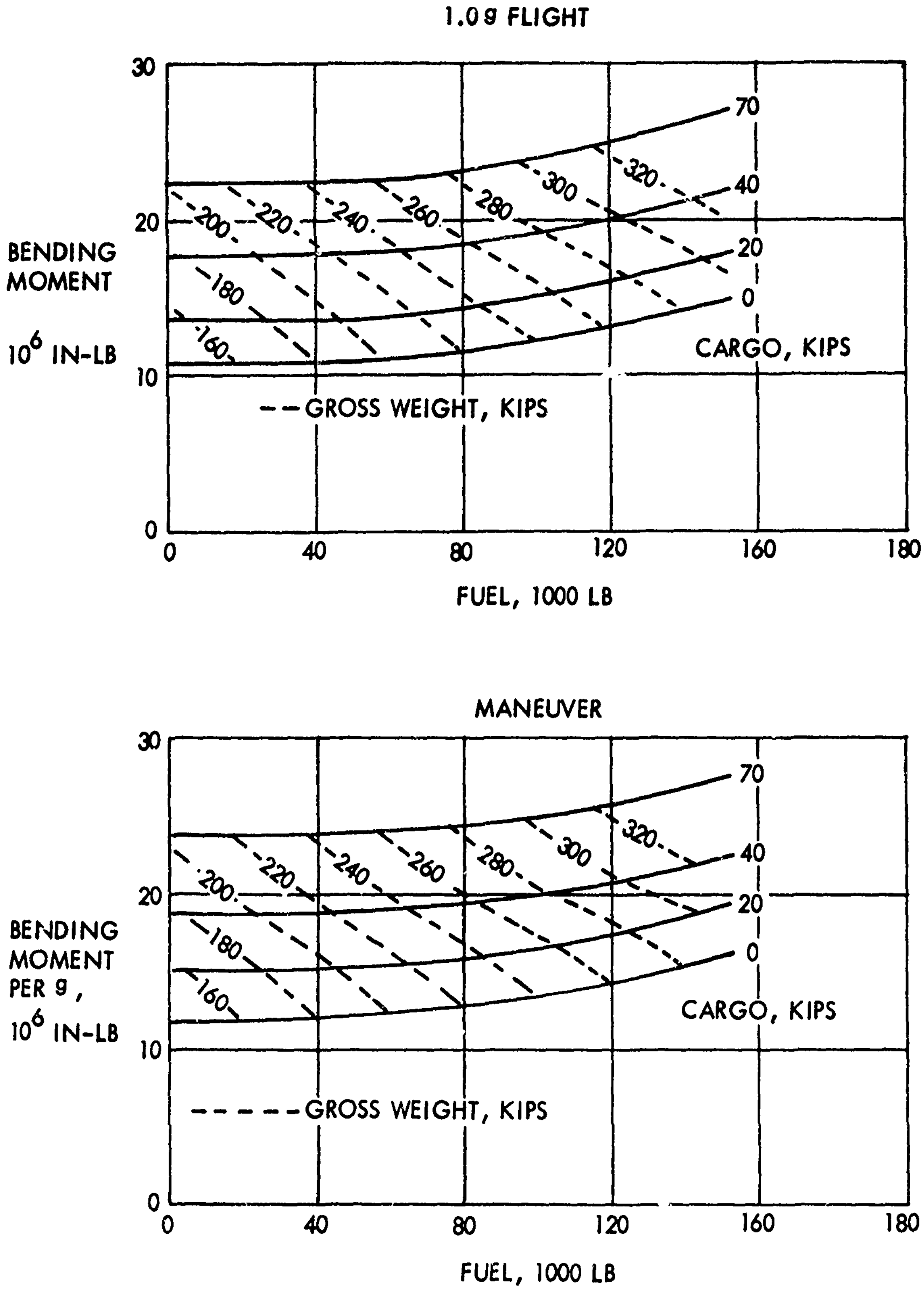
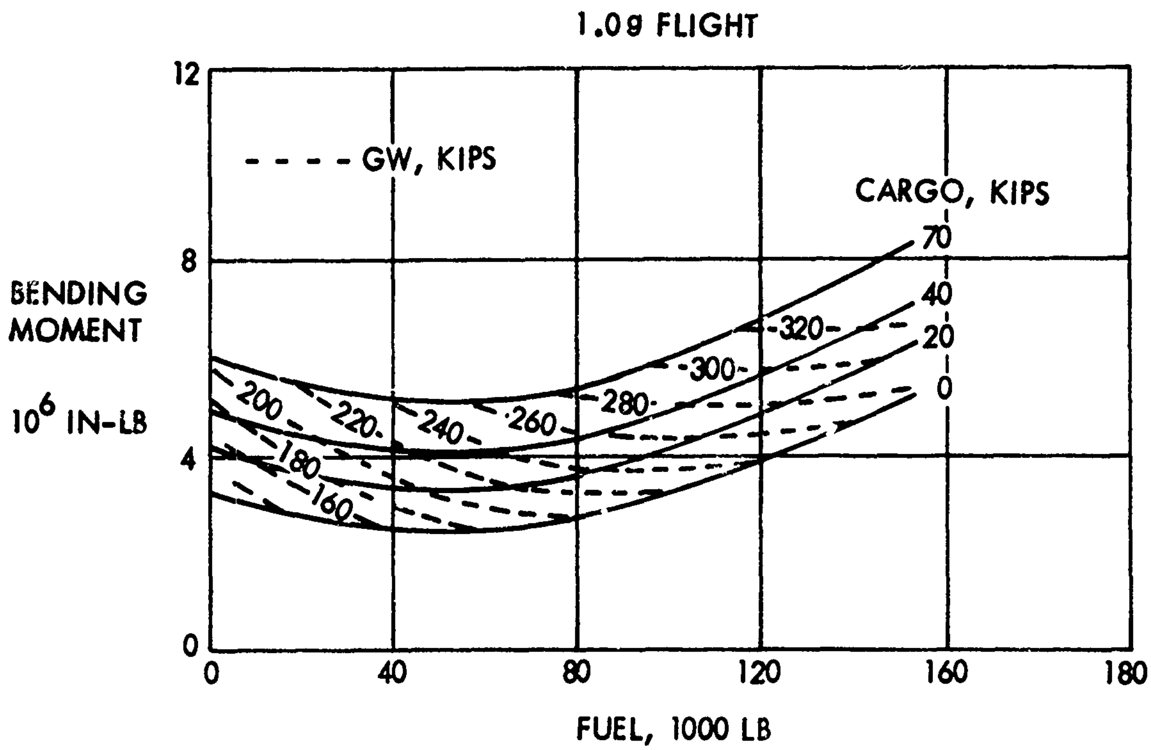


Figure 22 Unit Bending Moment W.S. 77.7, C-141A



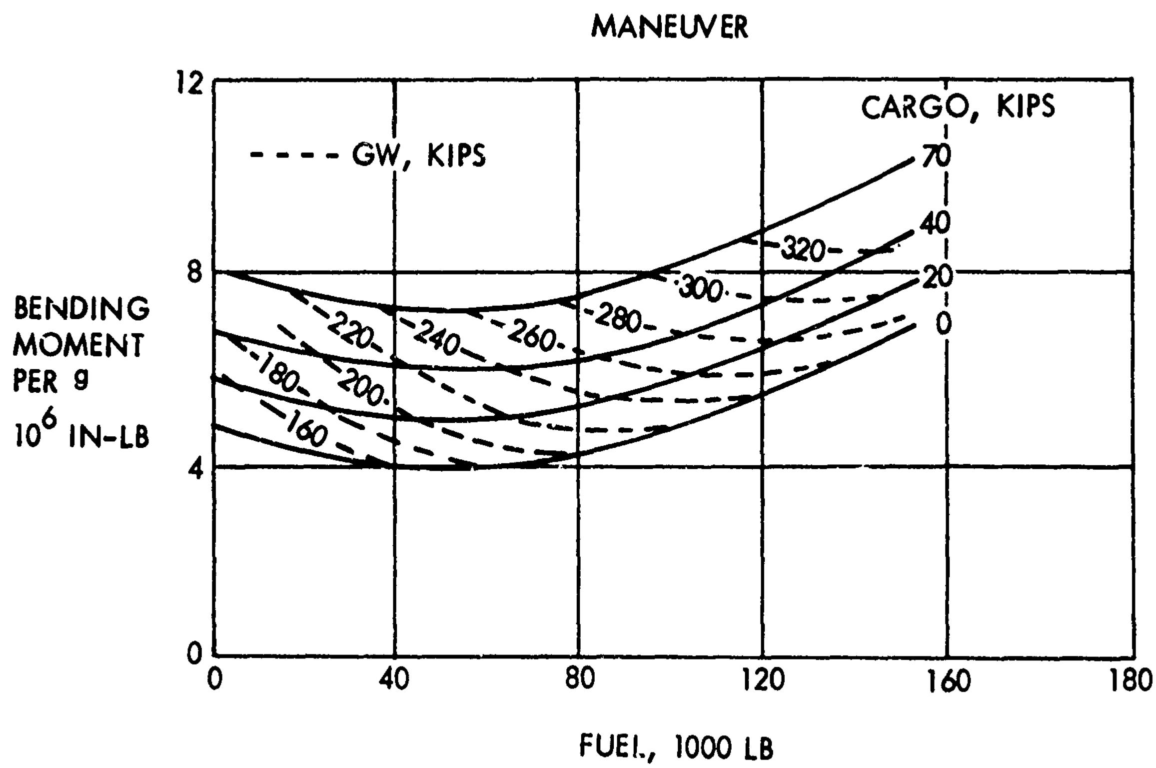


Figure 23 Unit Bending Moment W.S. 460, C-141A

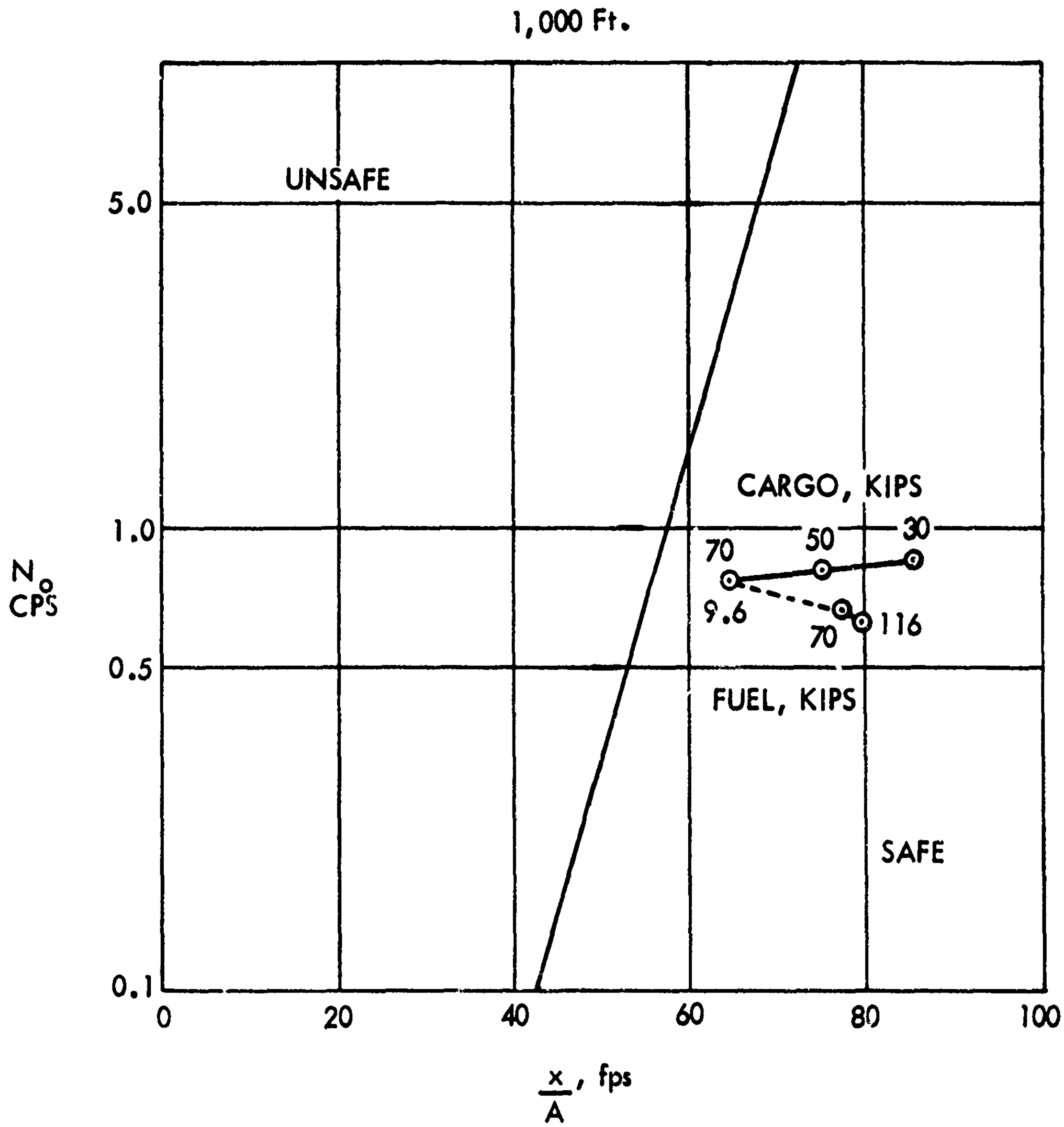


Figure 24 Preliminary (Perhaps Final) Design-Weight Comparison, C-141A

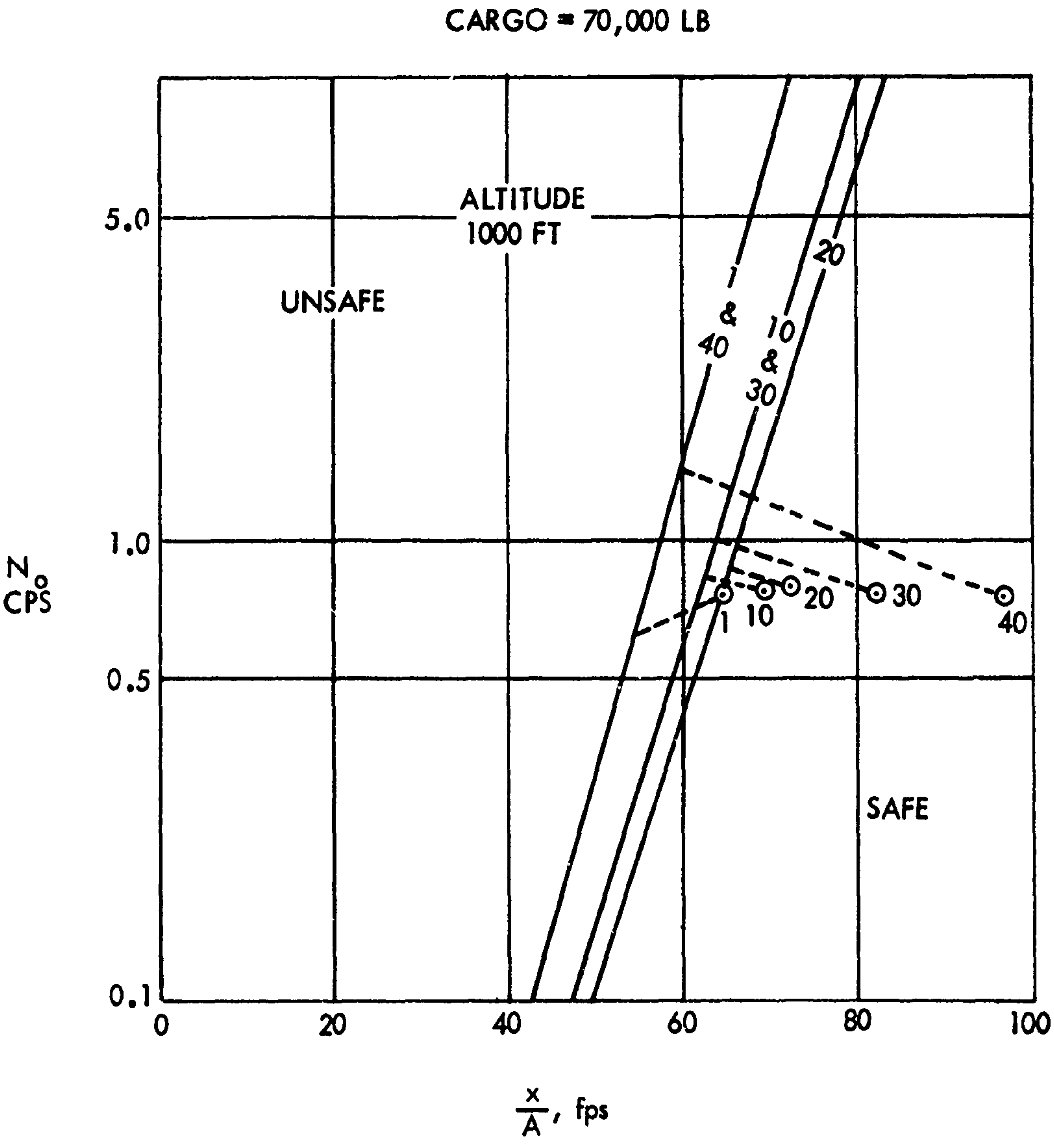


Figure 25 Preliminary (Perhaps Final) Design, C-141A

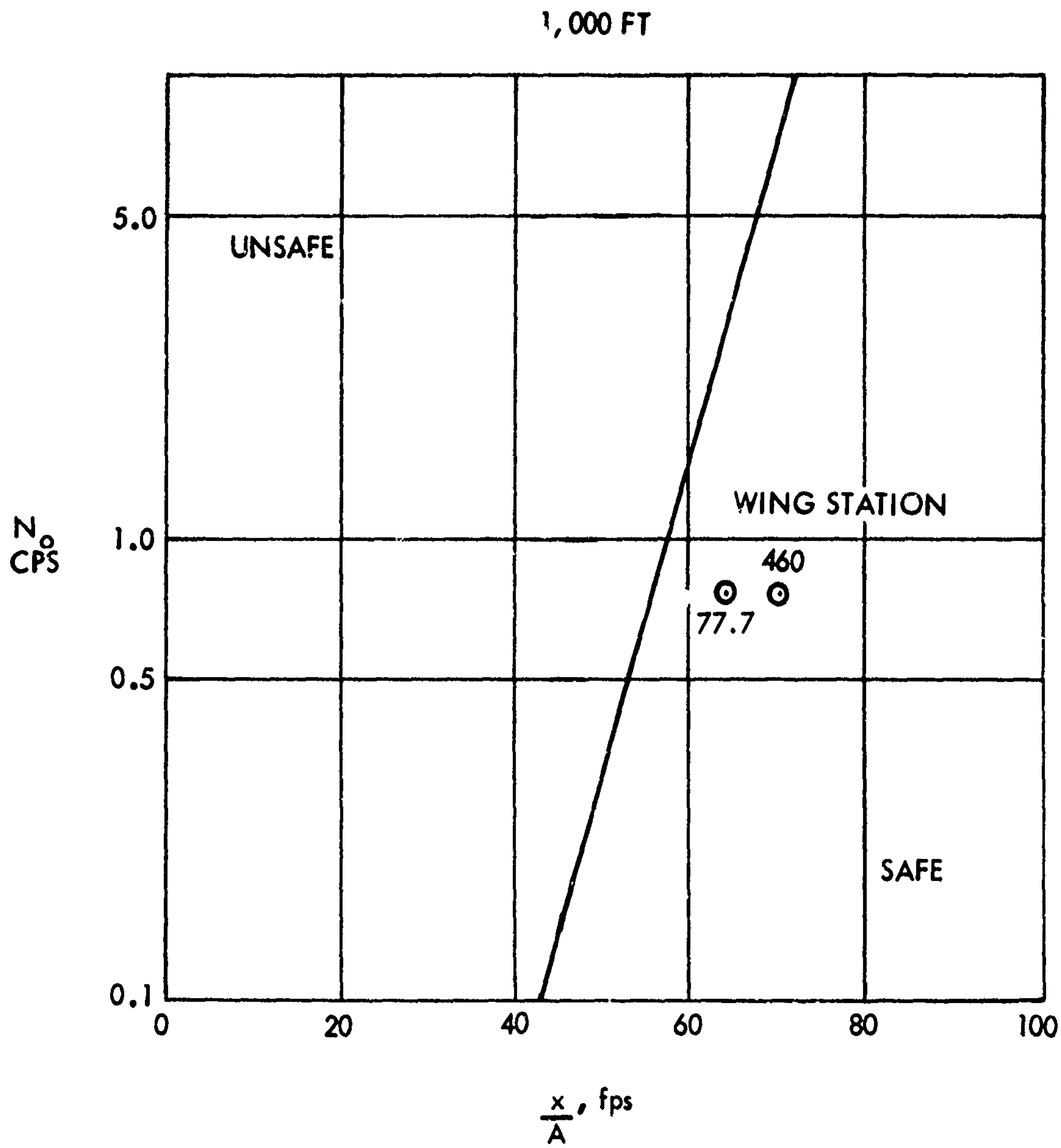


Figure 26 Preliminary (Perhaps Final) Design Critical Station, C-141A

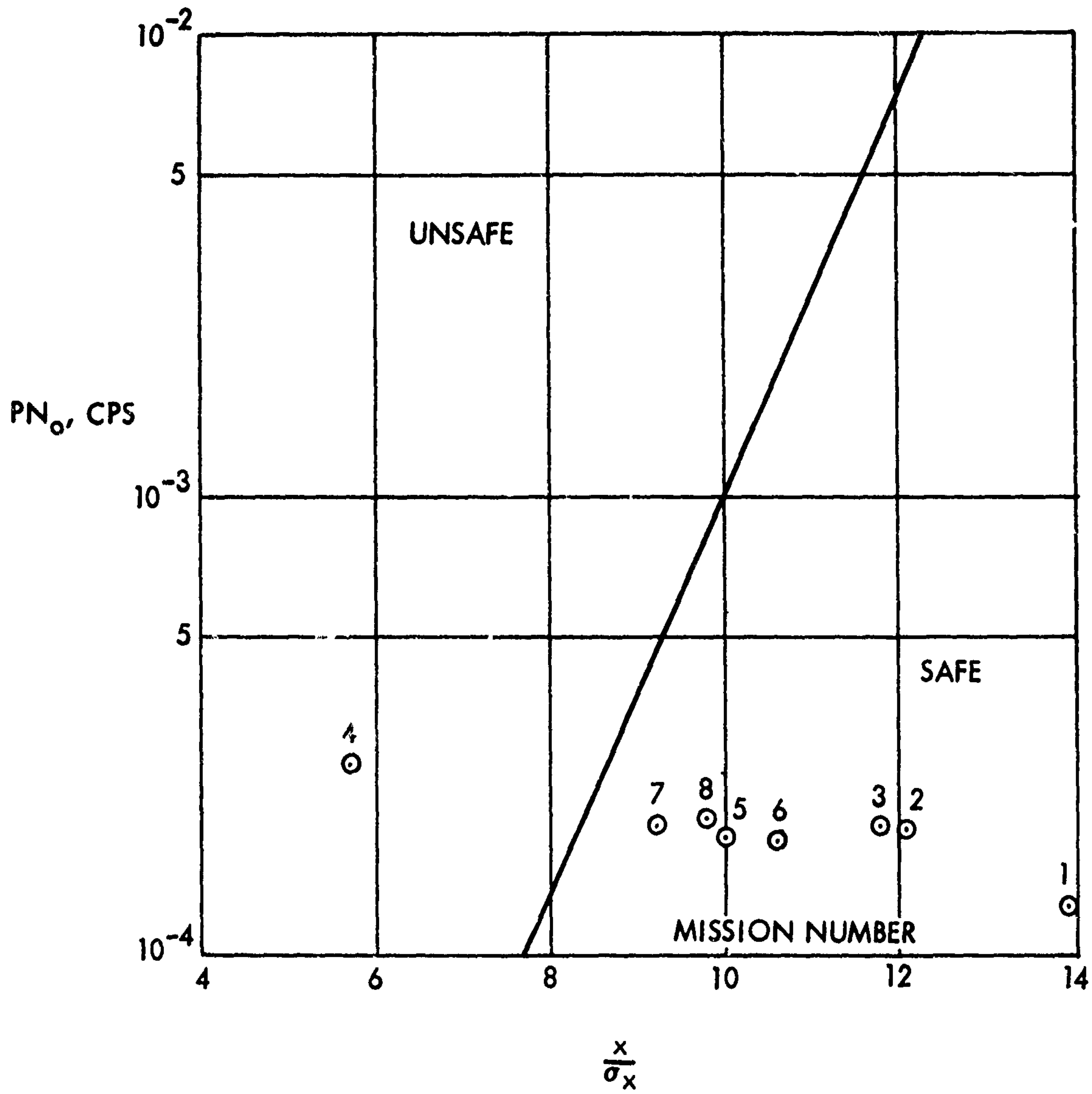


Figure 27 Composite Load Factor Design, C-141

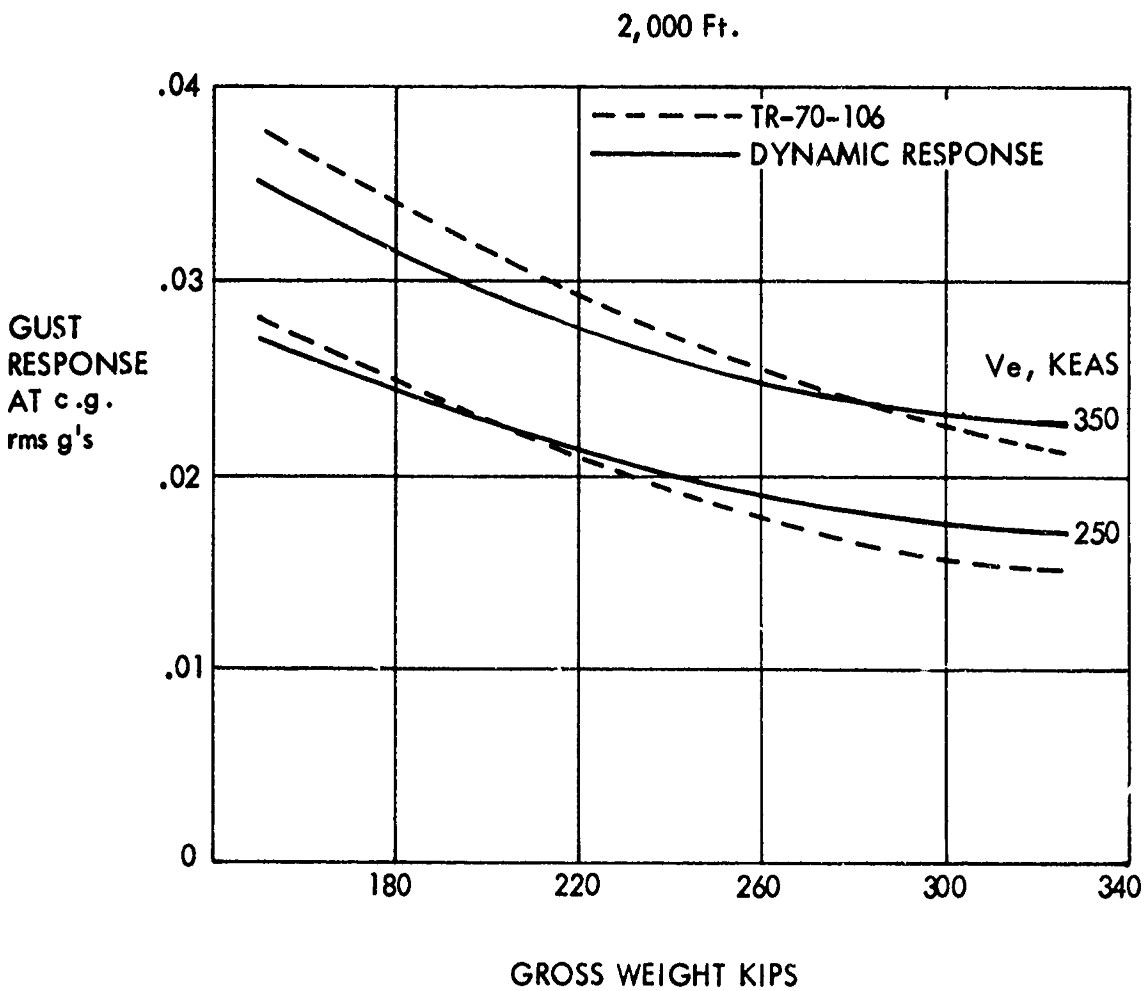


Figure 28 Comparison of rms c.g. Response, C-141A

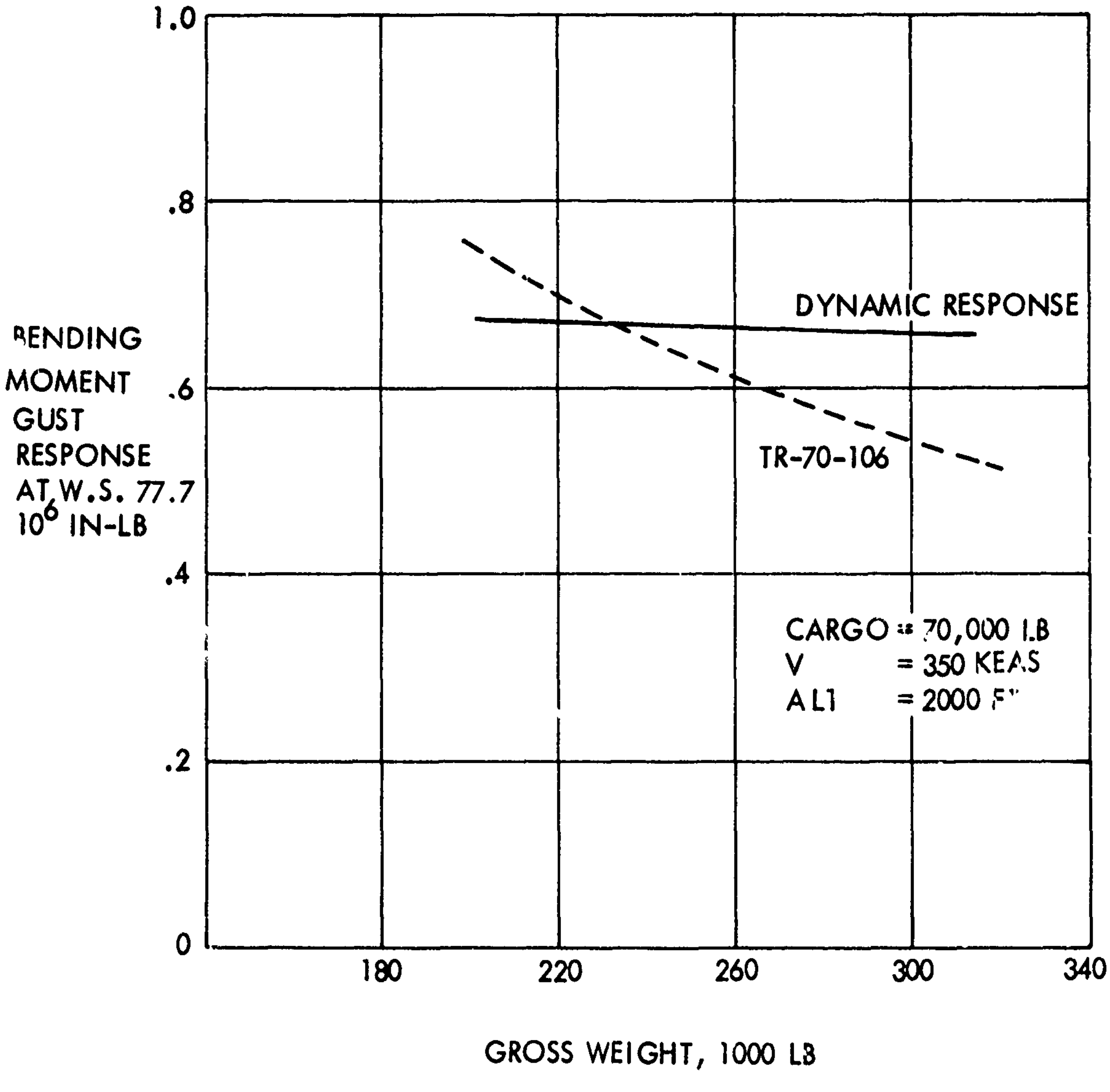


Figure 29 Comparison of rms Bending Moment W.S. 77.7, C-141A

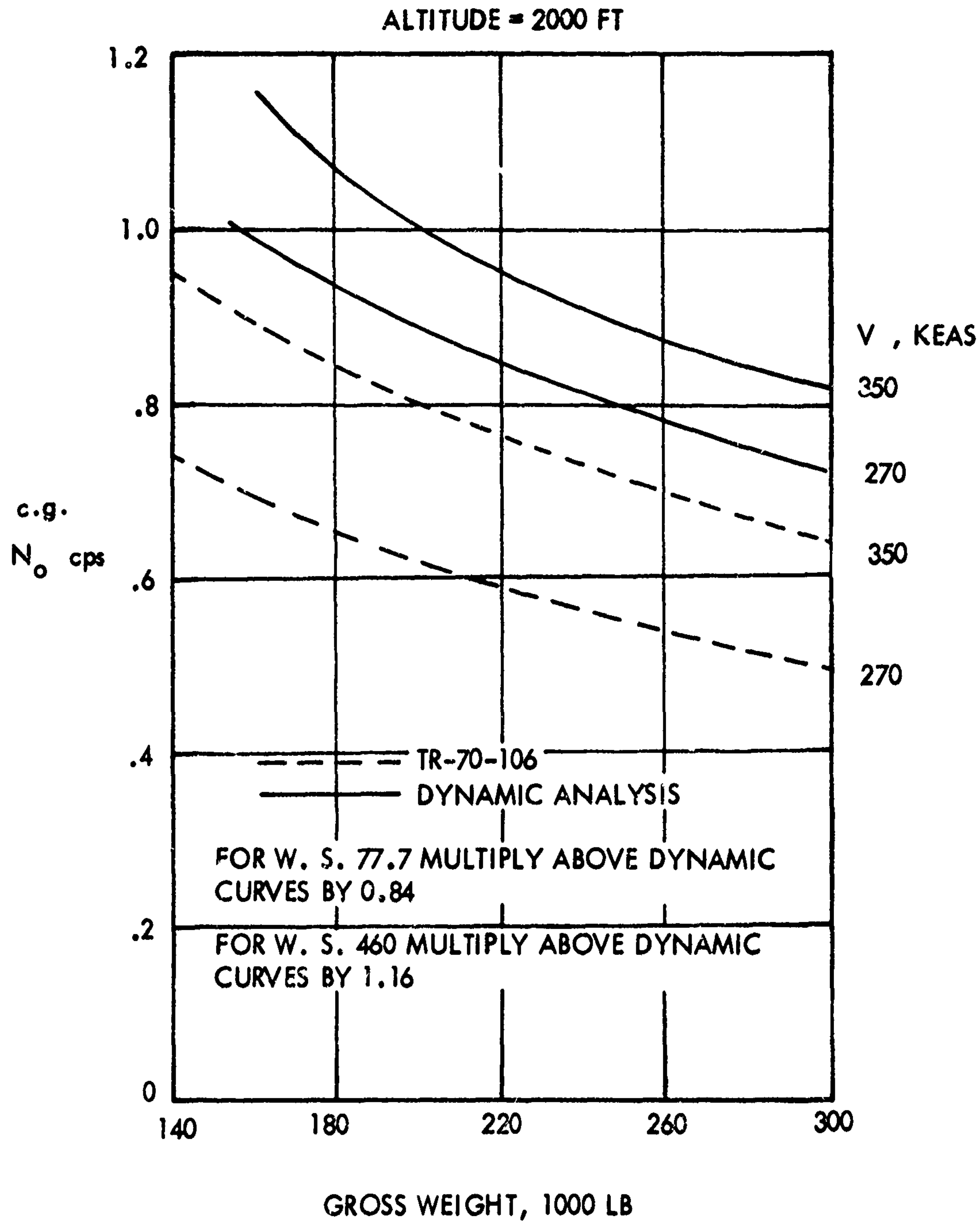


Figure 30 Comparison of Characteristic Frequencies, N_o, C-141A

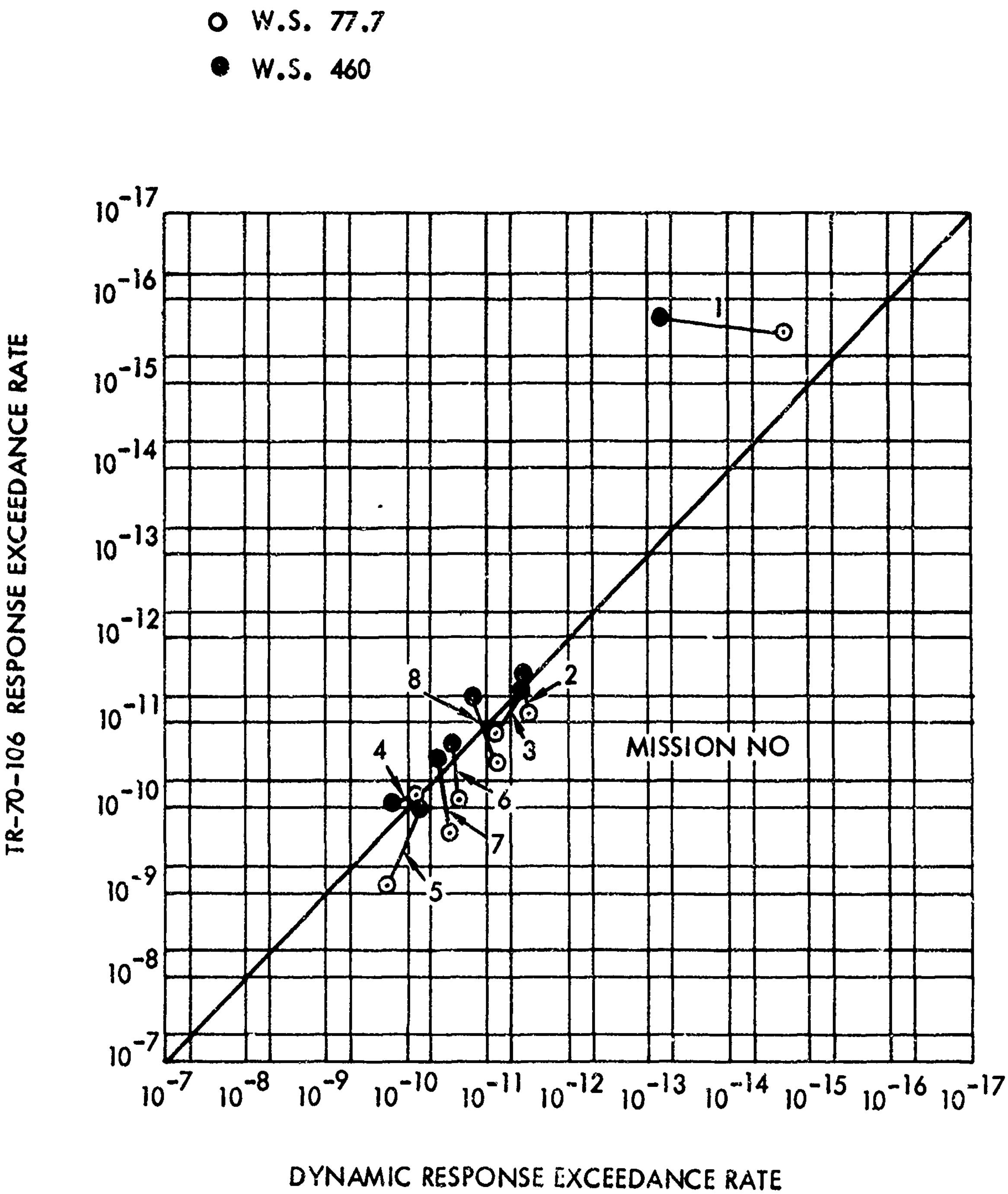


Figure 31 Comparison of Mission Limit Load Exceedance Rate, C-141A

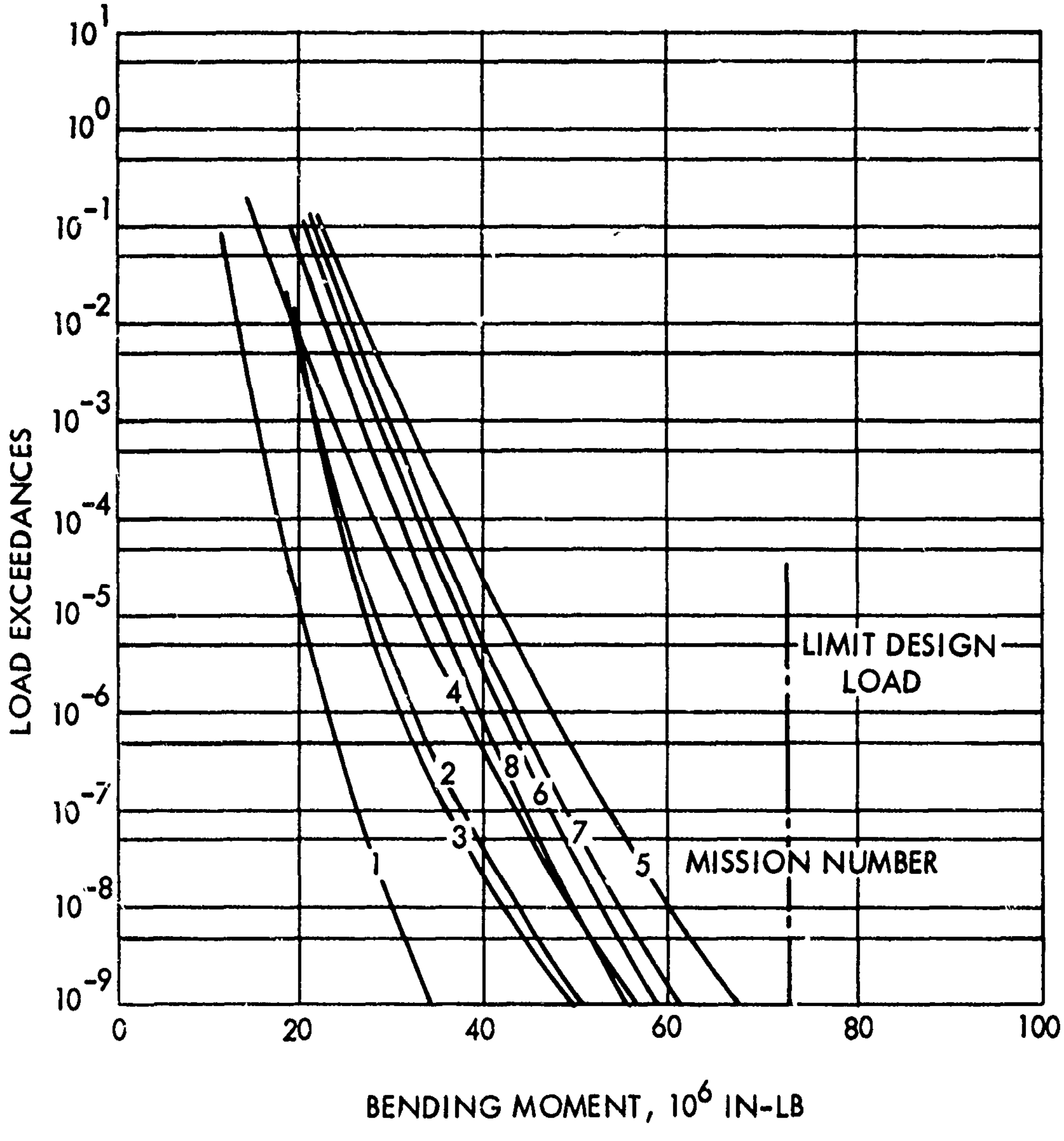


Figure 32 Wing Station 77.7 Moment Exceedance, C-141A

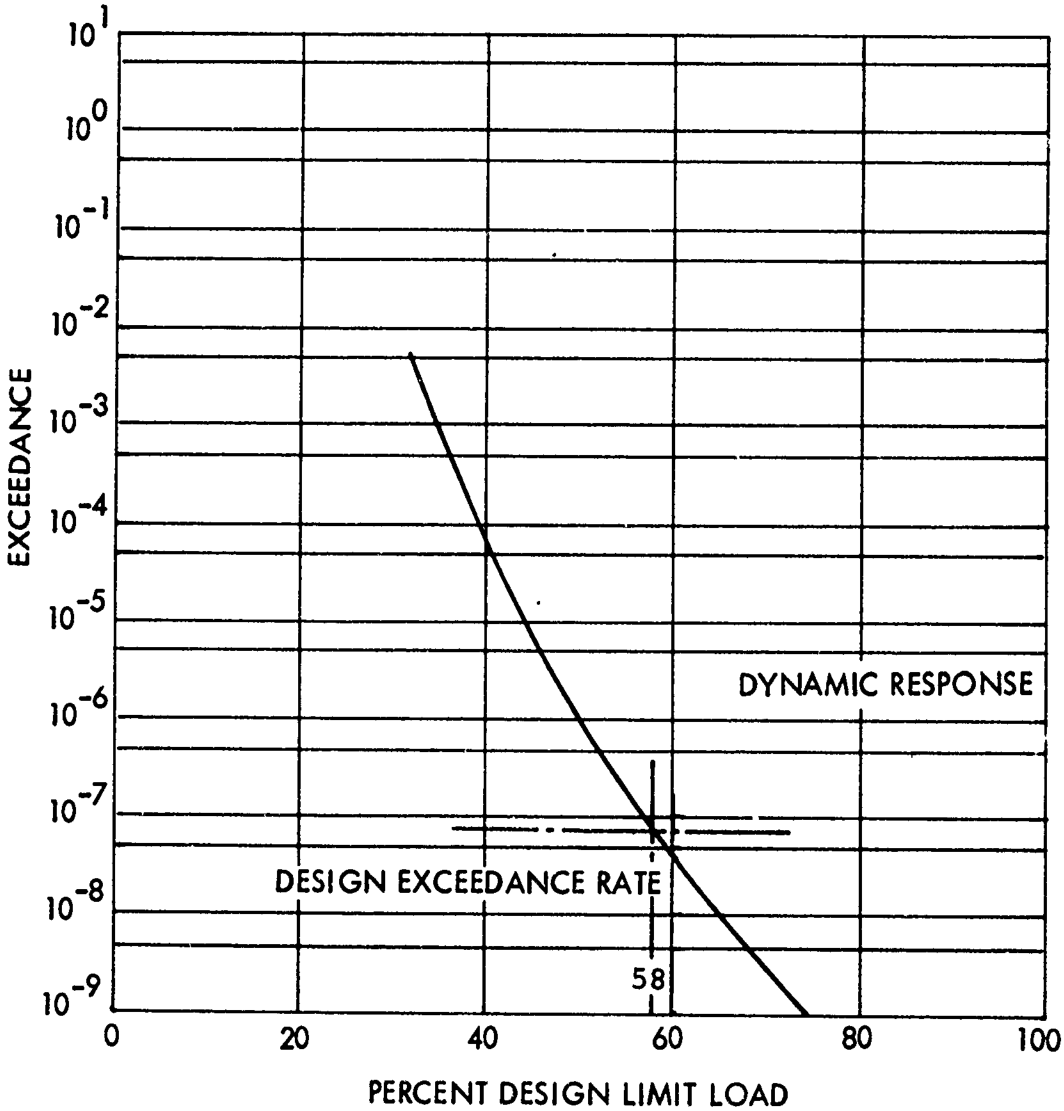


Figure 33 Mission Analysis Design Gust Load W.S. 77.7 C-141A

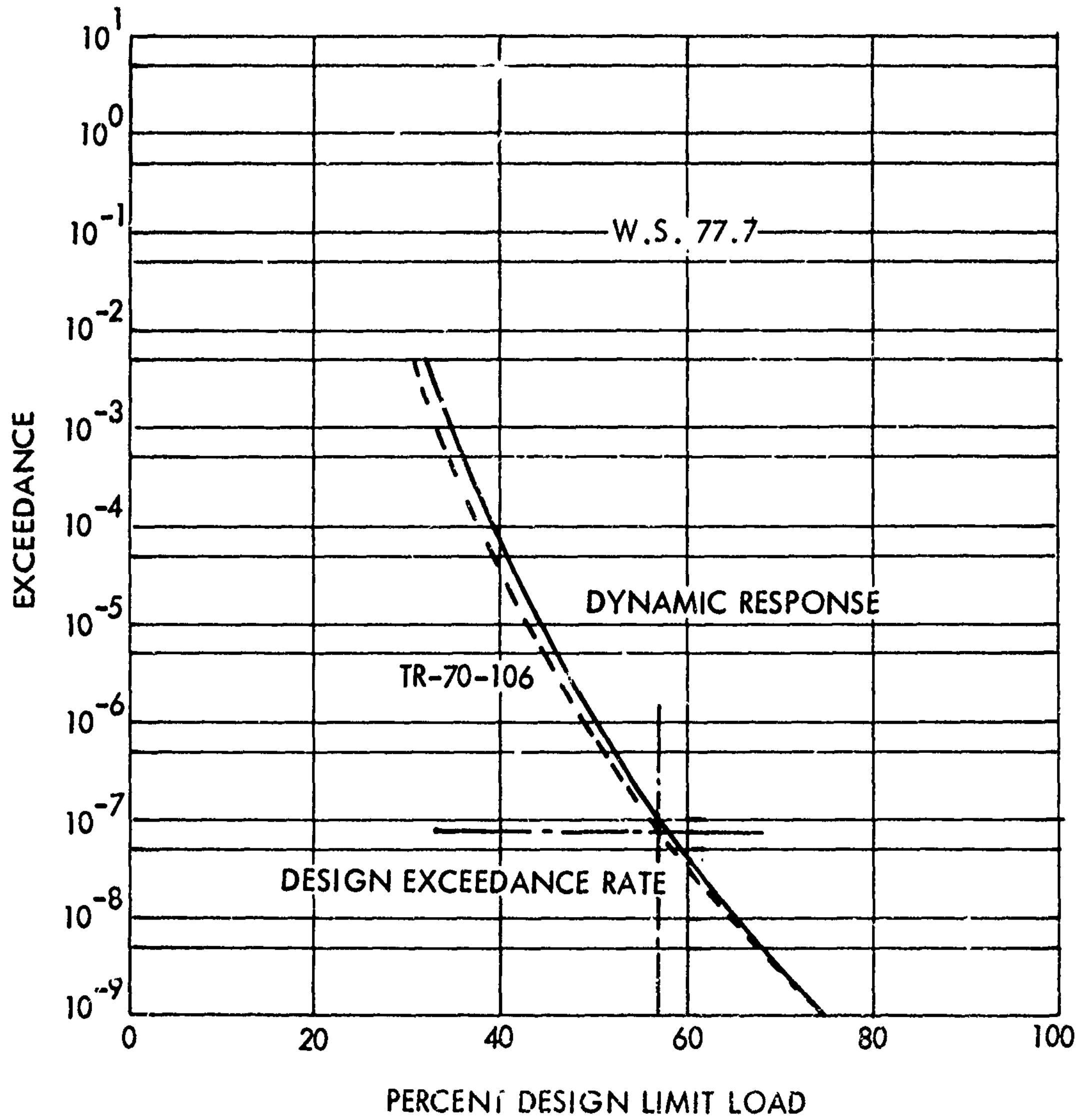


Figure 34 Comparison of Percent Limit Design Load, C-141A

SECTION V

C-130 ANALYSIS RESULTS

Basic Data

C-130 series aircraft are used in a multitude of missions. Each series has been structurally substantiated to Air Force criteria. Most recent gust criteria on the C-130 cre by dynamic magnification factor (DMF) applied to the results from the static gust loads formula. The initial mission for the C-130 was tactical with symmetrical maneuvering design load factors of +3.0 and -1.0. The nominal cargo for the tactical mission aircraft is 25,000 pounds. Later it was desired that the aircraft perform logistics and resupply missions as a cargo transport. The maneuver limits for this category aircraft are +2.5 and -1.0. Nominal cargo weights for this usage are 35,000 and 45,000 pounds. A speed altitude schedule was developed for each set of cargo weights. These operational flight envelopes are defined on Figure 35.

The C-130 is a straight wing aircraft and operates at what are considered as low speeds. Design manual derived response data are developed using the lift curve slope with elastic increments shown in Figure 36. Unit bending moment for Wing Root Station 61 and Wing Station 550 (70% semi-span) are given on Figures 37 and 38, respectively. Similar to the C-141A, the maximum payload at structural reserve fuel produces maximum unit bending moments.

Nine mission profiles are used in the most recent C-130B/E fatigue analyses. These missions are defined in Figure 39. Missions 1 and 2 are training. Mission 3 is the shuttle or resupply mission. This mission is divided into four sub-missions to obtain data on identical missions changing only the weights. Cargo is progressively off-loaded and fuel is used. The speed, altitude, and time of mission remain constant. Missions 4 and 5 are logistics. Airdrop is covered in Mission 6; storm reconnaissance is covered in Mission 7, support in Mission 8, and rescue/skyhook in Mission 9.

Preliminary Design Approach

Results of the preliminary design approach are given in Figures 40 through 44. Identification of each mission, by nominal cargo, is retained. The maximum speed for each nominal design cargo is included. An unsafe condition is indicated for the 35,000-pound and the 45,000-pound cargo missions at the applicable speed schedule for

altitudes below 10,000 feet. A safe margin exists at Wing Station 550 for all altitudes. Preliminary design results at an altitude of 1000 feet are given in Figure 44 for Wing Station 550.

The composite load factor approach indicates that the majority of the missions are on the unsafe side. Missions 3.1, 3.2, 3.3, and 3.4 are identical except for cargo and resulting gross weight. Decreasing weight results in reduced levels of safety. From a loads or stress evaluation, the heavier cargo weights will result in more critical gust conditions. This is substantiated with the data presented on Figures 50 and 51.

Figure 46 illustrates a possible use of the preliminary design approach. Speed altitude schedules were determined for the C-130 and compared to the current schedule. The power spectral density (PSD) derived schedule requires lower speeds below 10,000 feet and allows higher speeds at altitudes above 10,000 feet. The PSD derived speed schedule is the more desirable from a logistics operational point of view as it allows higher speeds at cruise altitudes.

Detail Design Approach

Detailed design is concerned with mission exceedance rate and evaluation of frequency or dynamic response. Comparison of the design manual one degree of freedom center of gravity response and dynamic response data is shown on Figure 47. Dynamic response data are correlated values from full scale dynamic response testing and are part of the C-130 data bank used in fatigue tracking programs. Bending moment response comparisons are given in Figure 48. Loads from the two methods compare more favorably than the accelerations. The loads are of prime importance in gust analyses. Zero crossings or characteristic frequencies are compared on Figure 49. The single degree of freedom method provides good overall estimates of gust response for the C-130 aircraft.

All of the results of the detailed design approach are given on Figure 50. The allowable exceedance rate of 7.0×10^{-8} is not exceeded for any of the missions. The high cargo missions result in minimum margins. In general, the design manual using one degree of freedom response results in conservative loadings for the C-130 aircraft. Figure 51 presents the bending moment exceedance curves for each of the missions. Limit design moment is included for comparison.

A total load exceedance curve is developed using the defined utilizations and is presented in Figure 52. Comparison of total load exceedances between the one degree of freedom and dynamic analysis is given on Figure 53. The contribution of Mission 3.1 for the dynamic response solution is the primary reason for this result being 5 percent above the design manual value. This can also be deduced from the mission exceedance rate data shown on Figure 50. Seven percent of the time results in nearly half the mission exceedance loadings.

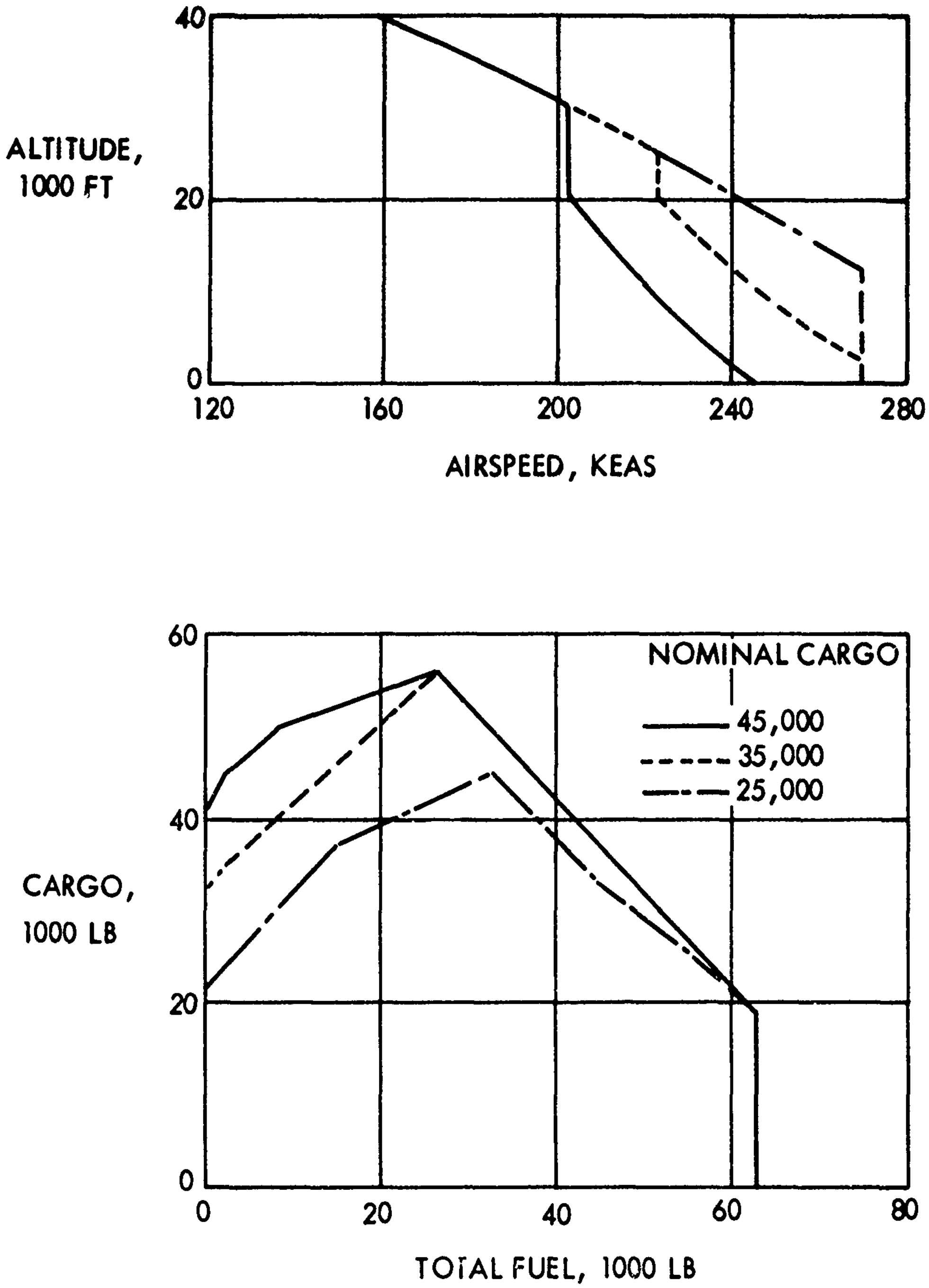
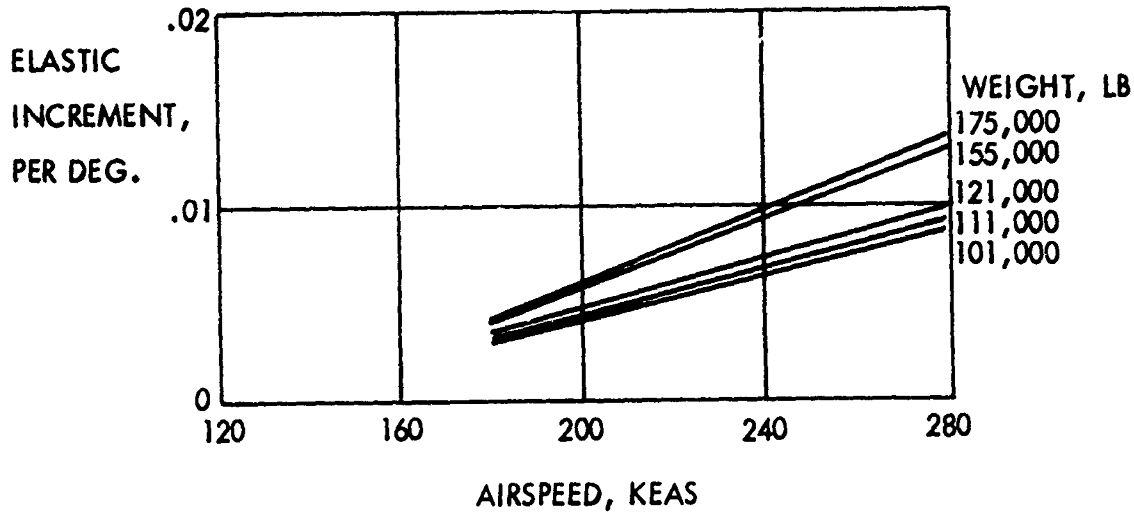


Figure 35 Operational Flight Envelope, C-130



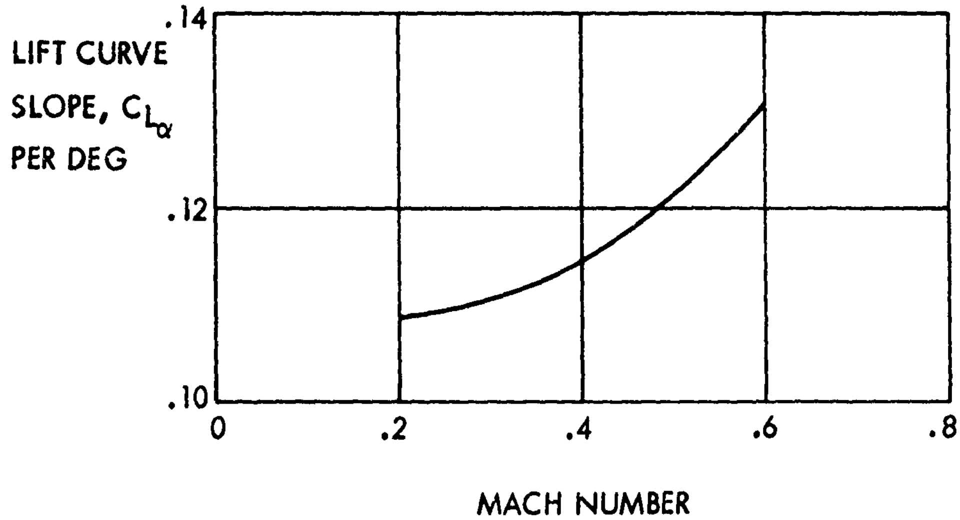


Figure 36 Lift Curve Slope, C-130

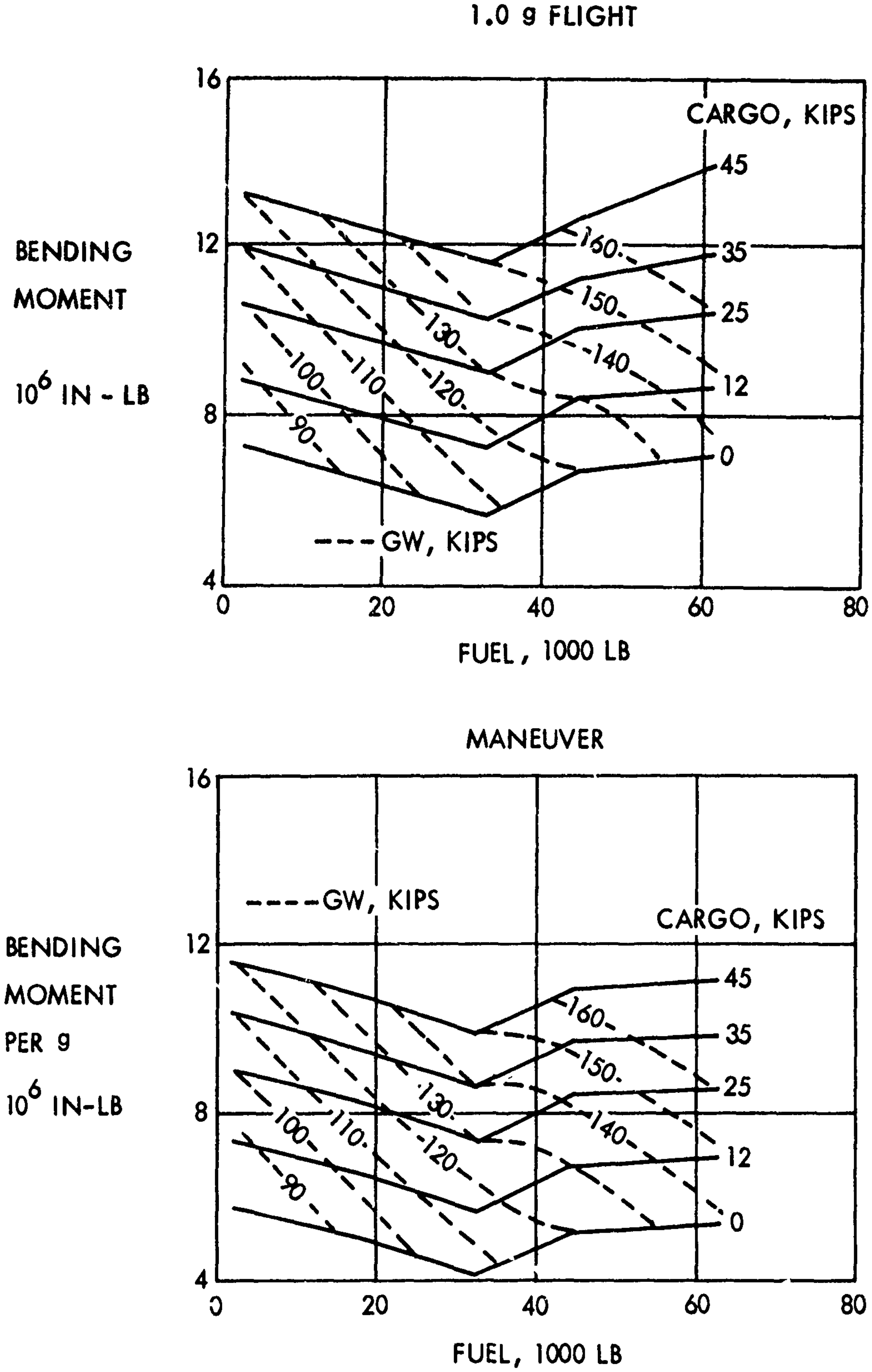
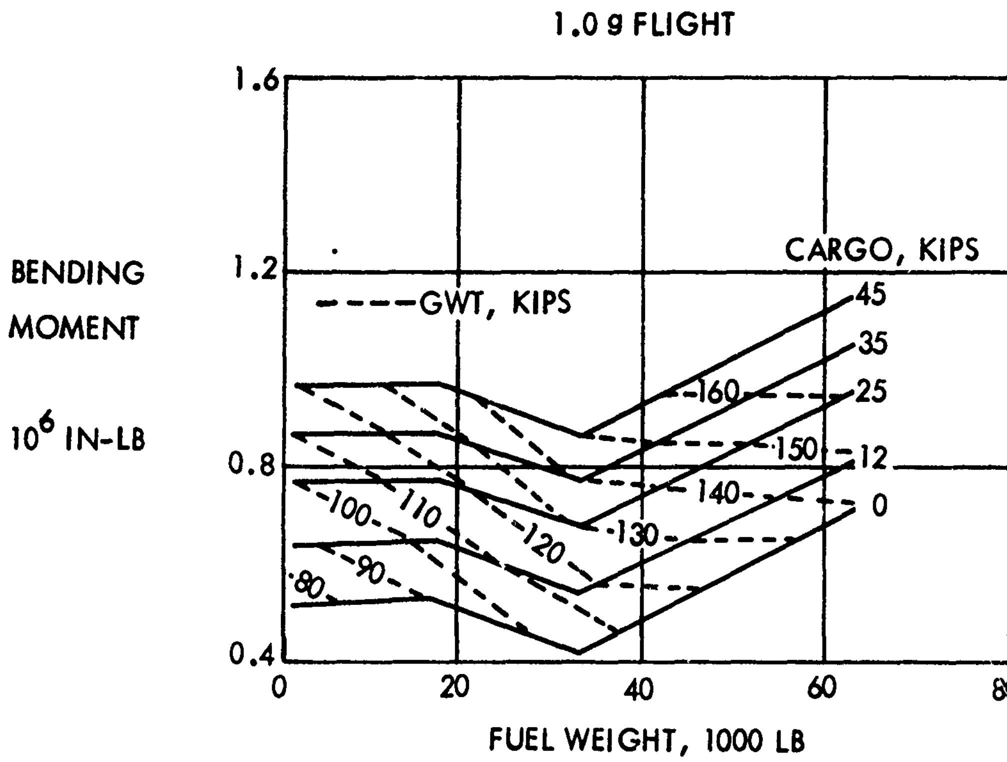


Figure 37 Unit Bending Moment W.S. 61, C-130



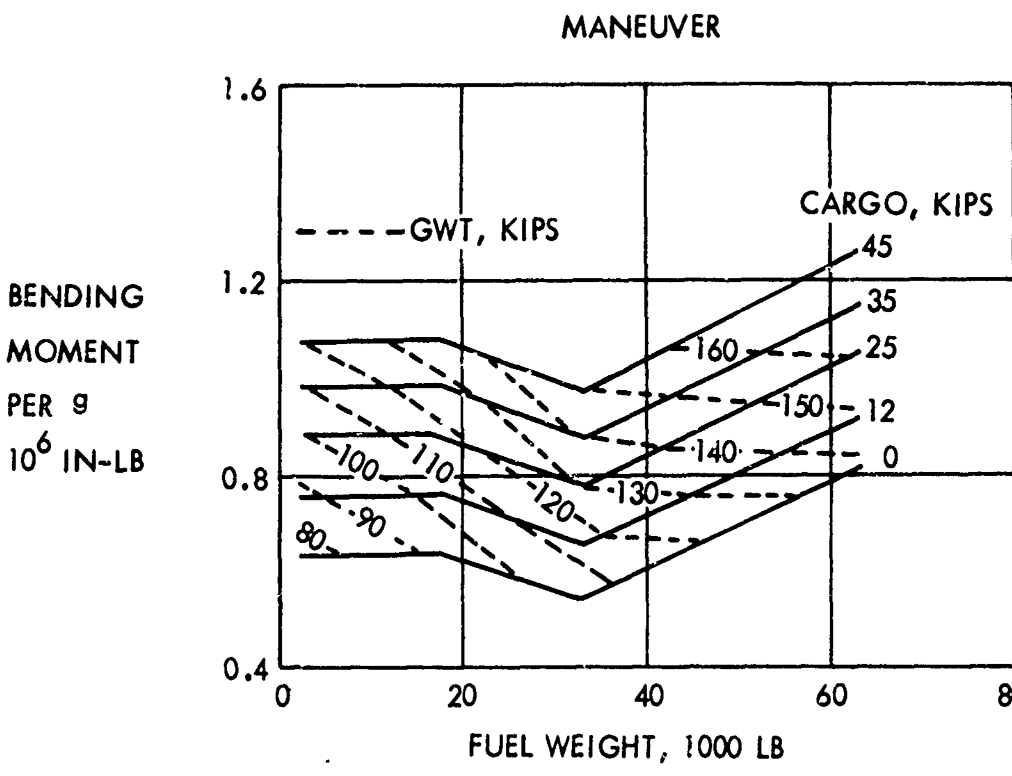


Figure 38 Unit Bending Moments W.S. 550, C-130

C-130 MISSION 1

SEGMENT	1	2	3	4	5	6	
TIME	18	63	6	91	82	57	MINUTES
ALTITUDE	7500	20000	7500	1000	1000	20000	FEET
SPEED	170	200	250	150	150	200	KEAS
GROSS WT	112000	109000	105000	97000	93000	85000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.05

C-130 MISSION 2

SEGMENT	1	2	3	4	5	6	
TIME	20	34	33	40	71	42	MINUTES
ALTITUDE	7500	20000	1000	1000	1000	3000	FEET
SPEED	170	170	150	150	130	170	KEAS
GROSS WT	113000	111000	110000	102000	98000	92000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.08

C-130 MISSION 3.1

SEGMENT	1	2	3	4	5	6	
TIME	2	4	16	17	4	2	MINUTES
ALTITUDE	500	3000	5000	5000	3000	500	FEET
SPEED	170	170	250	250	250	250	KEAS
GROSS WT	135000	134000	132000	130000	129000	129000	POUNDS
CARGO WT	33000	33000	33000	33000	33000	33000	POUNDS

UTILIZATION -0.067

C-130 MISSION 3.2

SEGMENT	1	2	3	4	5	6	
TIME	2	4	16	17	4	2	MINUTES
ALTITUDE	500	3000	5000	5000	3000	500	FEET
SPEED	170	170	250	250	250	250	KEAS
GROSS WT	119000	119000	117000	115000	114000	114000	POUNDS
CARGO WT	25000	25000	25000	25000	25000	25000	POUNDS

UTILIZATION - 0.067

Figure 39 Design Mission Profiles, C-130

C-130 MISSION 3.3

SEGMENT	1	2	3	4	5	6	
TIME	2	4	16	17	4	2	MINUTES
ALTITUDE	500	3000	5000	5000	3000	500	FEET
SPEED	170	170	250	250	250	250	KEAS
GROSS WT	104000	104000	102000	100000	99000	98500	POUNDS
CARGO WT	17000	17000	17000	17000	17000	17000	POUNDS

UTILIZATION - 0.067

C-130 MISSION 3.4

SEGMENT	1	2	3	4	5	6	
TIME	2	4	16	17	4	2	MINUTES
ALTITUDE	500	3000	5000	5000	3000	500	FEET
SPEED	170	170	250	250	250	250	KEAS
GROSS WT	90200	90000	88000	86000	84500	84000	POUNDS
CARGO WT	9000	9000	9000	9000	9000	9000	POUNDS

UTILIZATION - 0.067

C-130 MISSION 4.0

SEGMENT	1	2	3	4	5	6	
TIME	9	9	72	72	9	9	MINUTES
ALTITUDE	5000	15000	21000	21000	15000	5000	FEET
SPEED	170	170	210	210	250	250	KEAS
GROSS WT	143000	142000	136000	130000	129000	128000	POUNDS
CARGO WT	35000	35000	35000	35000	35000	35000	POUNDS

UTILIZATION - 0.14

C-130 MISSION 5.0

SEGMENT	1	2	3	4	5	6	
TIME	13	12	120	216	16	13	MINUTES
ALTITUDE	7500	15000	20500	22700	17000	7500	FEET
SPEED	180	180	210	210	250	250	KEAS
GROSS WT	135000	133000	129000	117000	109000	109000	POUNDS
CARGO WT	22000	22000	22000	22000	22000	22000	POUNDS

UTILIZATION - 0.33

Figure 39 Design Mission Profiles, C-130 (Continued)

C-130 MISSION 6

SEGMENT	1	2	3	4	5	6	
TIME	2	58	9	12	6	13	MINUTES
ALTITUDE	500	1000	1500	1000	1000	500	FEET
SPEED	170	250	130	130	250	250	KEAS
GROSS WT	118000	116000	114000	100000	99000	98000	POUNDS
CARGO WT	13000	13000	13000	0	0	0	POUNDS

UTILIZATION - 0.07

C-130 MISSION 7

SEGMENT	1	2	3	4	5	6	
TIME	24	168	180	178	60	30	MINUTES
ALTITUDE	7500	10000	10000	10000	10000	7500	FEET
SPEED	230	200	180	200	230	230	KEAS
GROSS WT	134000	125000	111000	99000	91000	88000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.03

C-130 MISSION 8

SEGMENT	1	2	3	4	5	6	
TIME	24	72	54	174	258	18	MINUTES
ALTITUDE	7500	18000	18000	20000	30000	15000	FEET
SPEED	180	180	205	205	170	170	KEAS
GROSS WT	140000	134000	129000	117000	95000	88000	POUNDS
CARGO WT	11000	8000	3000	0	0	0	POUNDS

UTILIZATION - 0.01

C-130 MISSION 9

SEGMENT	1	2	3	4	5	6	
TIME	69	31	77	93	33	27	MINUTES
ALTITUDE	500	15000	1000	300	1000	500	FEET
SPEED	235	230	230	230	190	170	KEAS
GROSS WT	111000	106000	101000	91000	86000	83000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.02

Figure 39 Design Mission Profiles, C-130 (Continued)

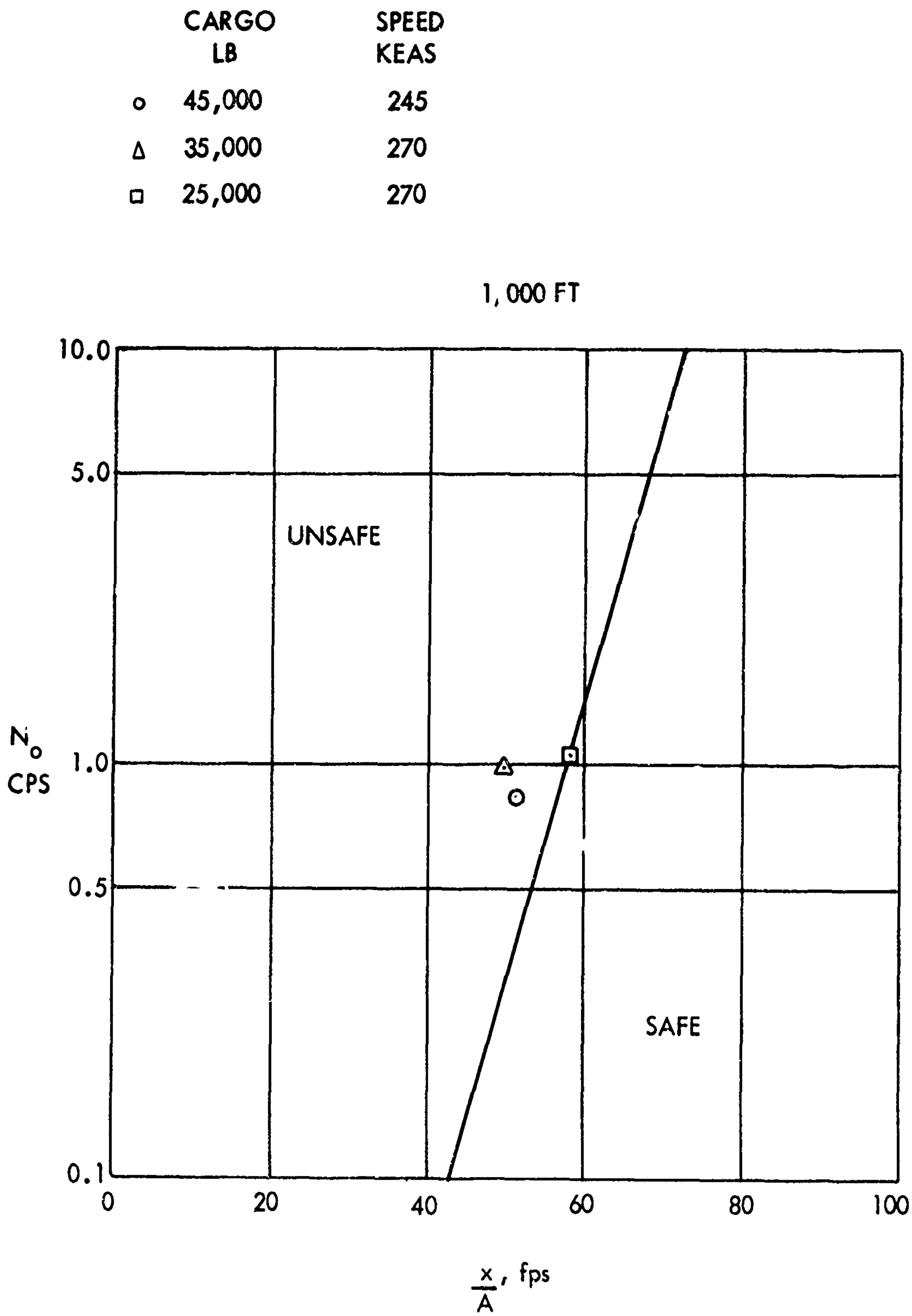


Figure 40 Preliminary (Perhaps Final) Design 1000 Ft. C-130

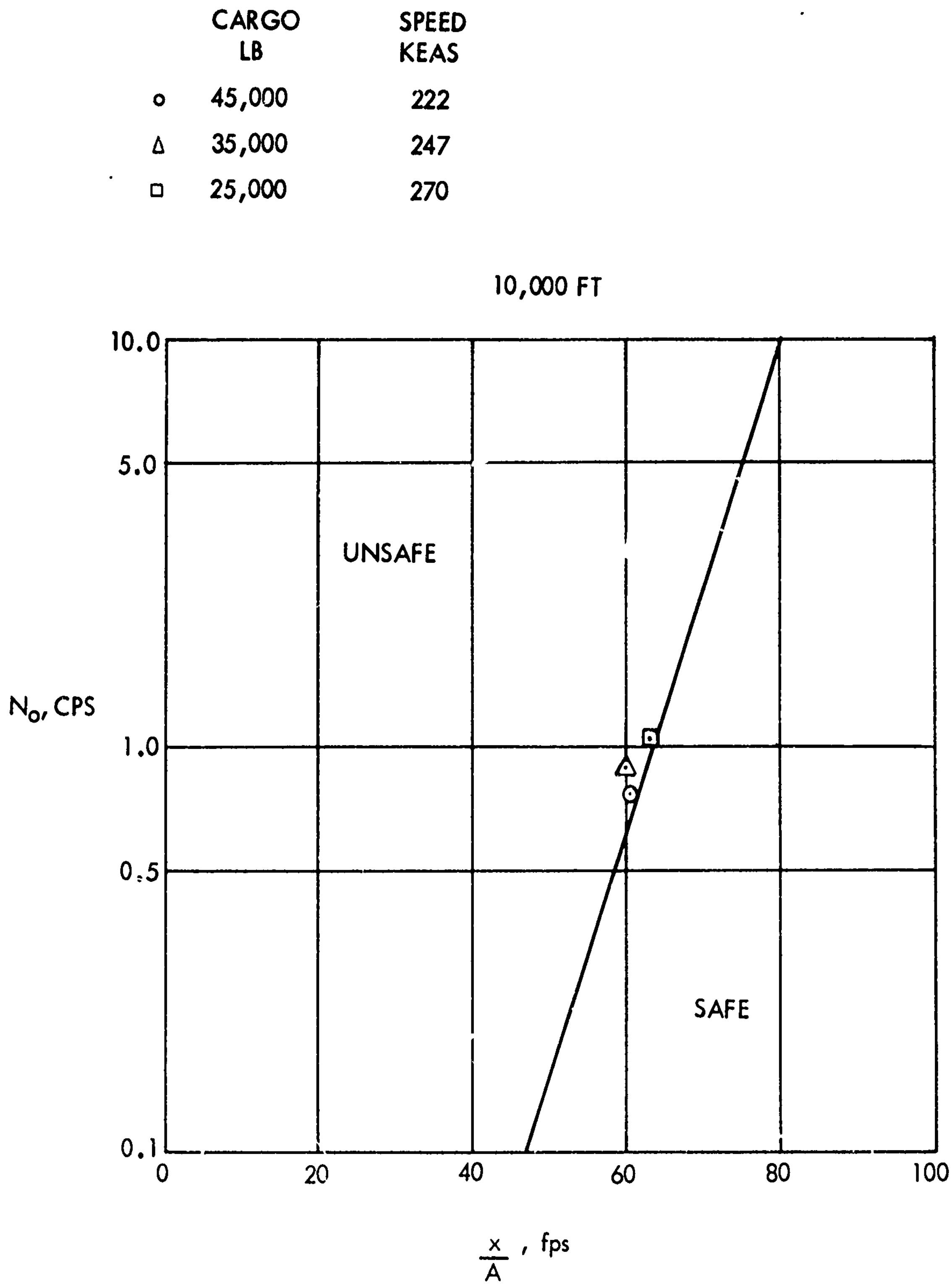


Figure 41 Preliminary (Perhaps Final) Design 10,000 Ft, C-130

	CARGO LB	SPEED KEAS
○	45,000	203
△	35,000	223
□	25,000	243

20,000 FT

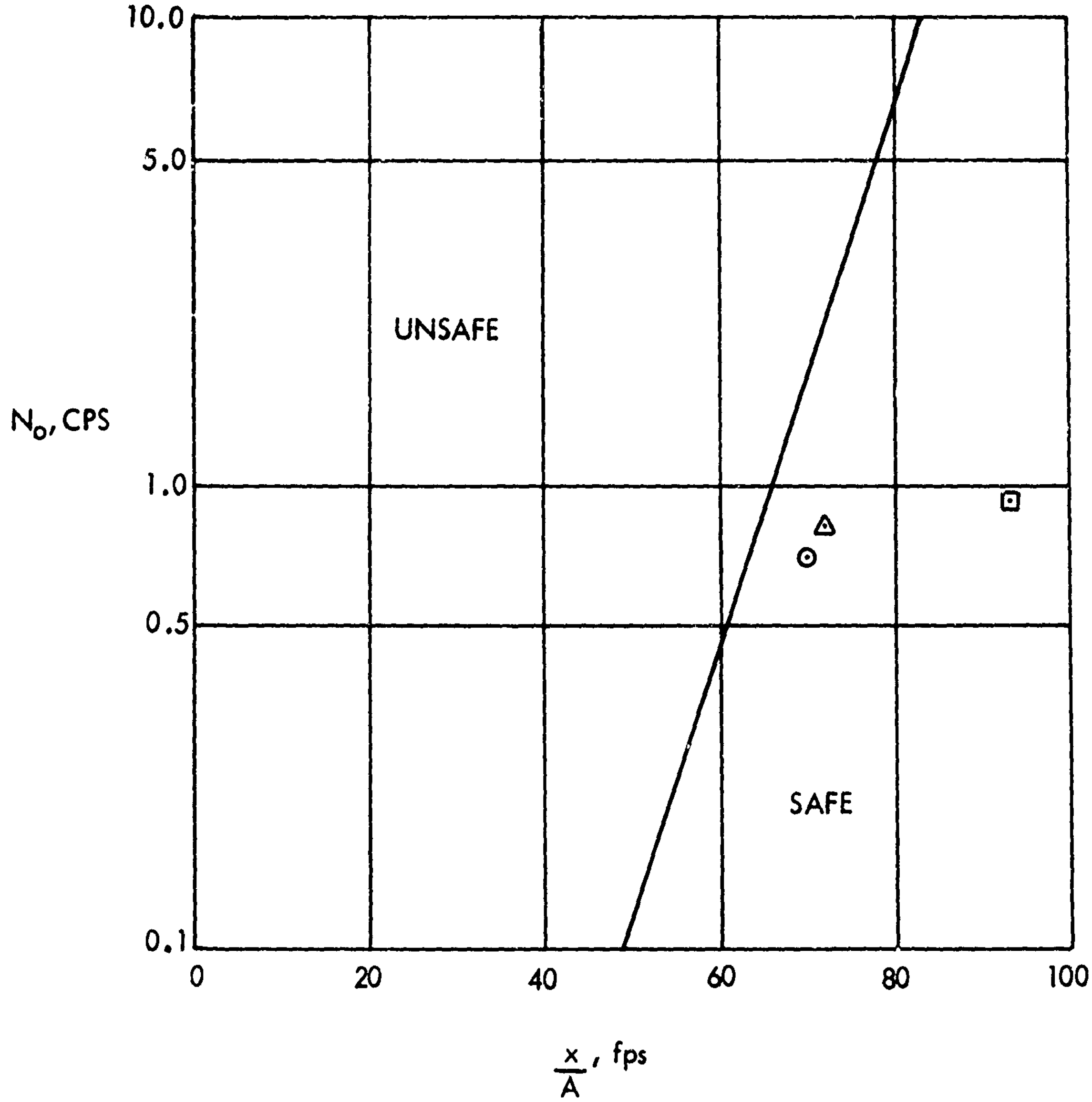


Figure 42 Preliminary (Perhaps Final) Design, 20,000 Ft., C-130

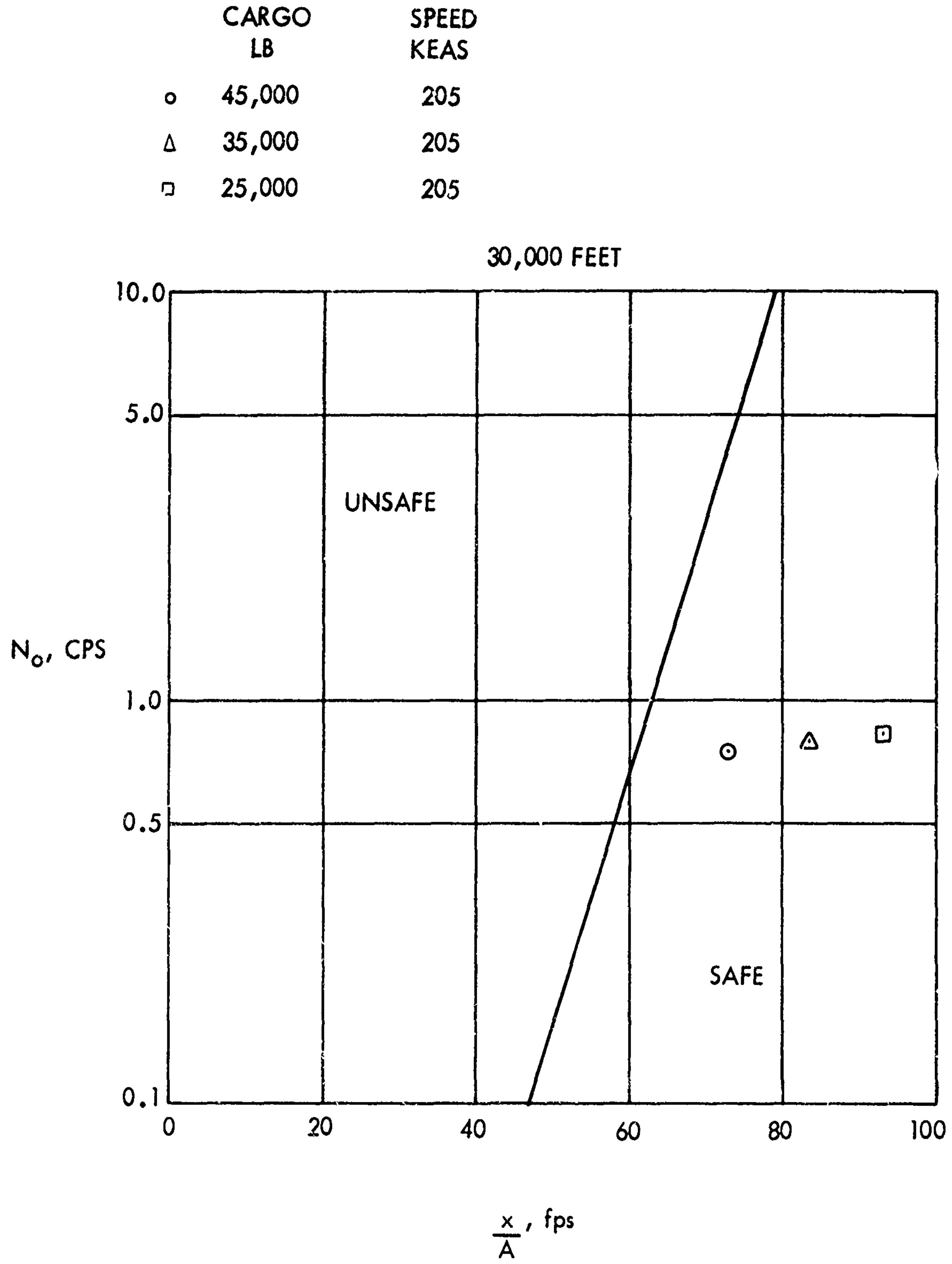


Figure 43 Preliminary (Perhaps Final) Design 30,000 Ft., C-130

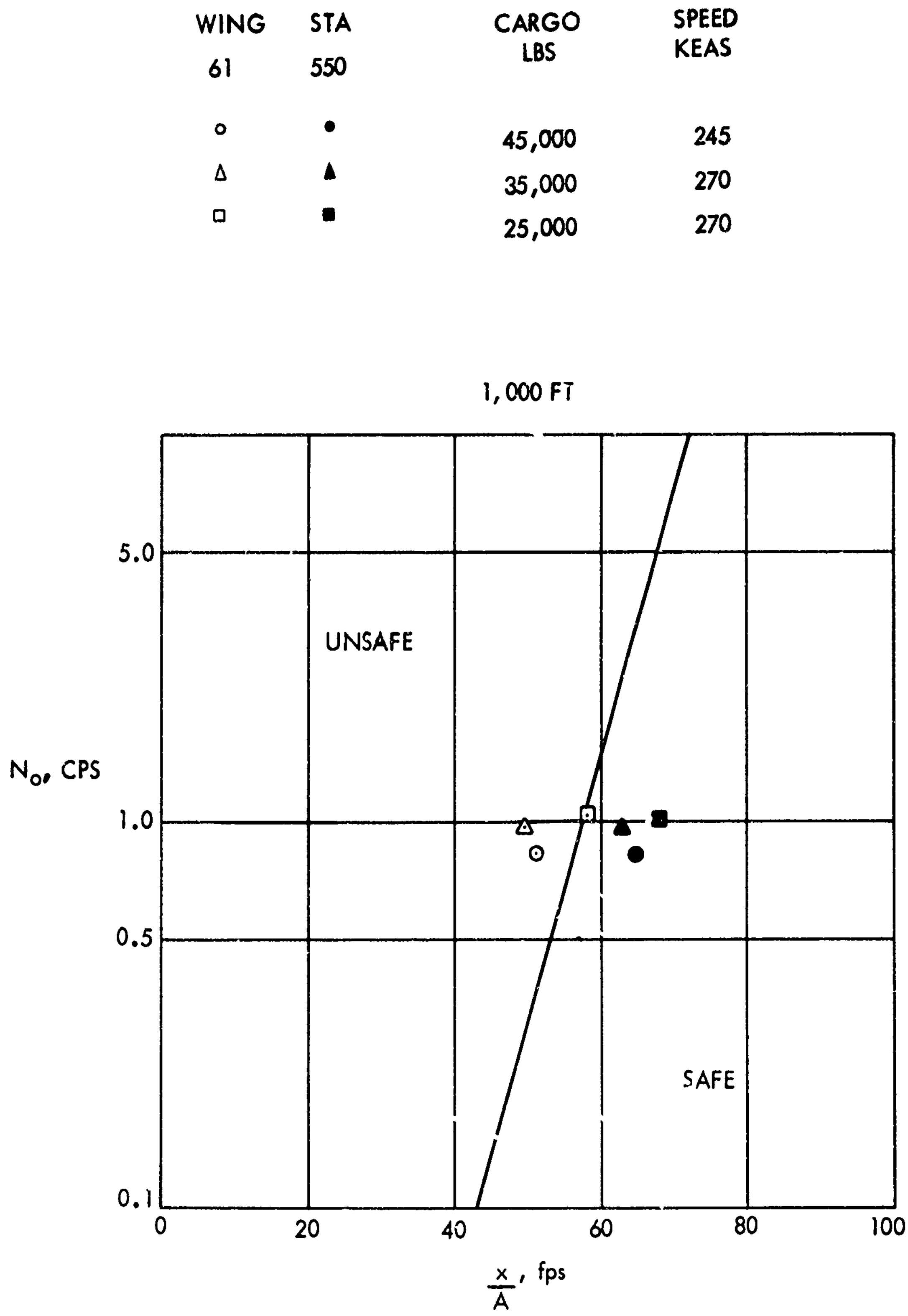


Figure 44 Preliminary (Perhaps Final) Design Wing Station Comparison, C-130

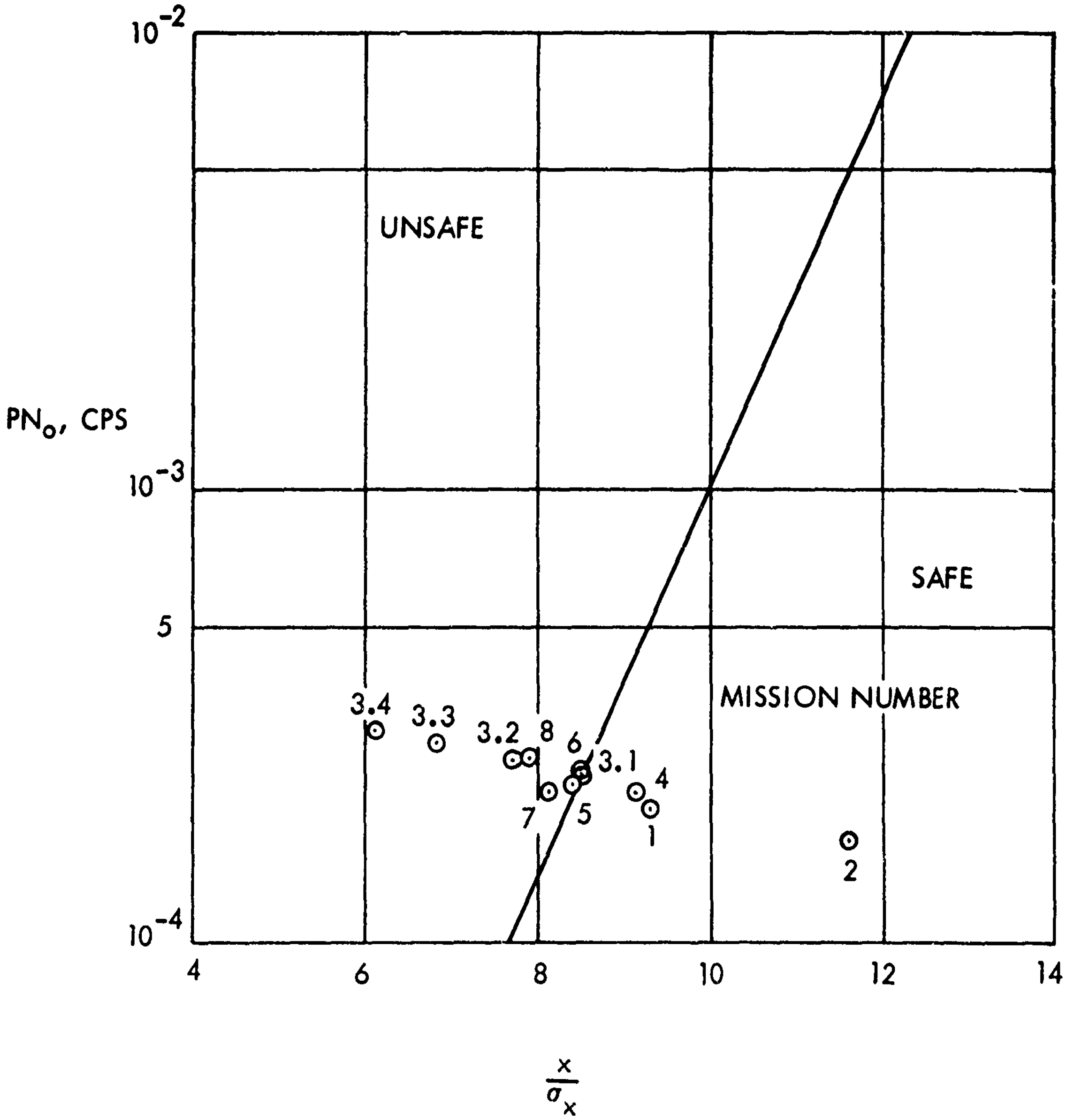


Figure 45 Composite Load Factor Design, C-130

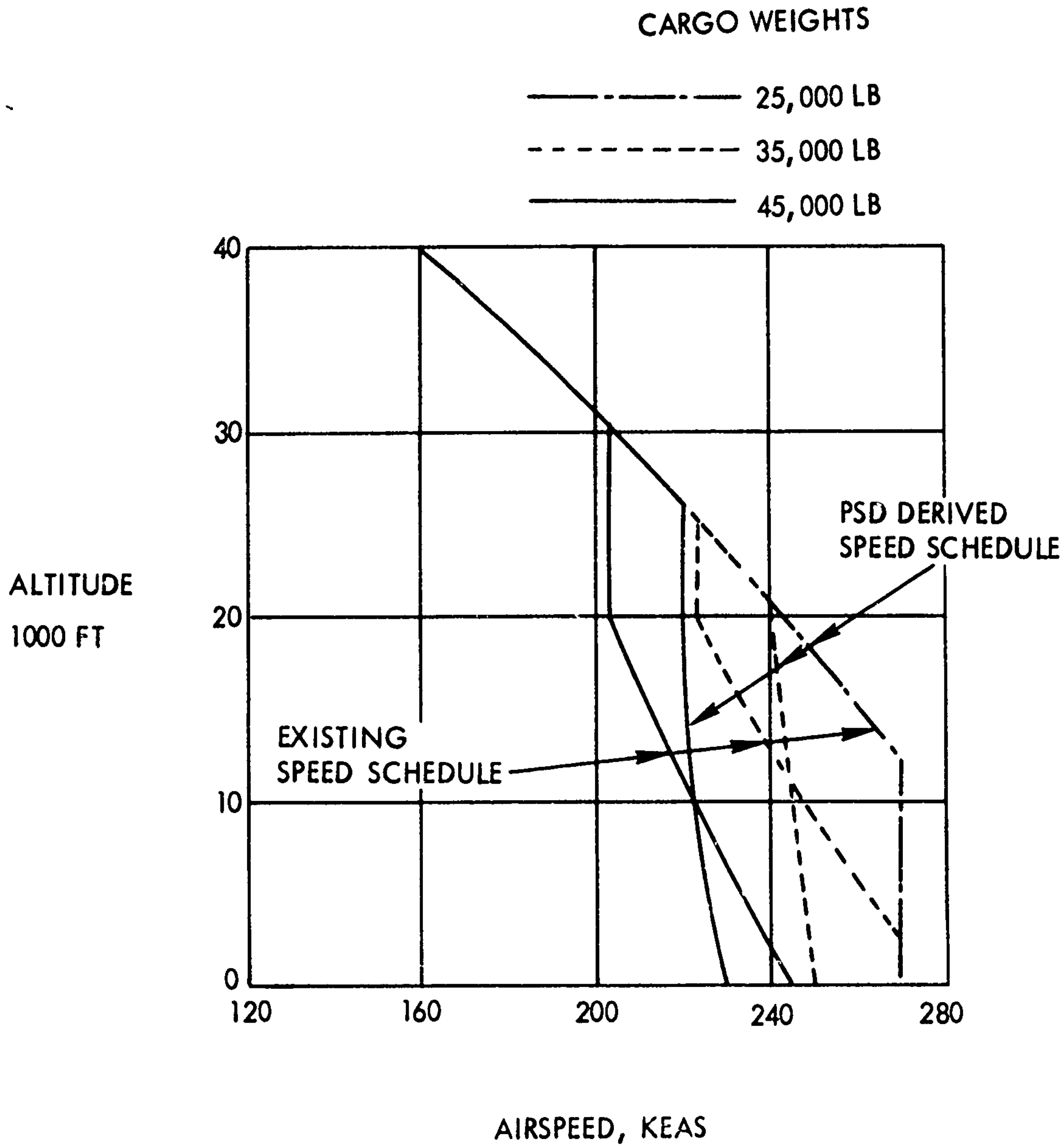


Figure 46 Operational Flight Envelope Comparison, C-130

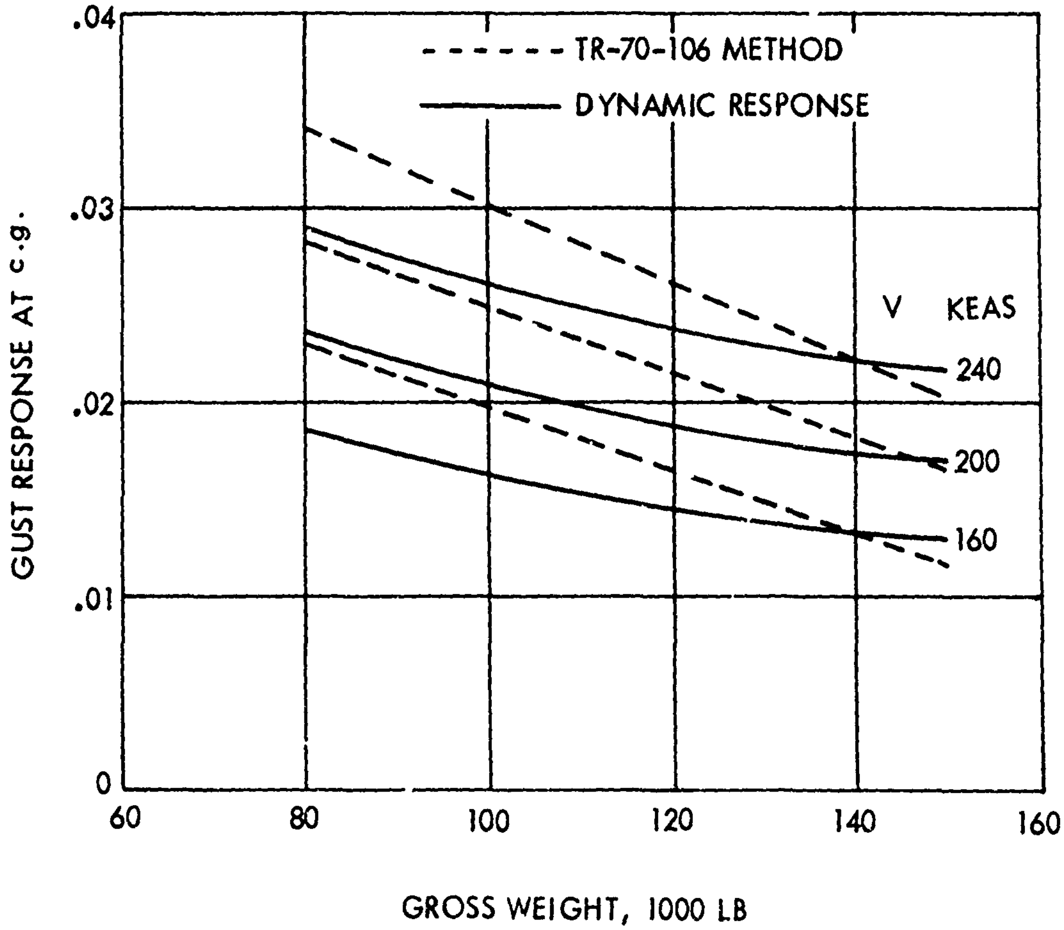


Figure 47 Comparison of rms c.g. Response, C-130

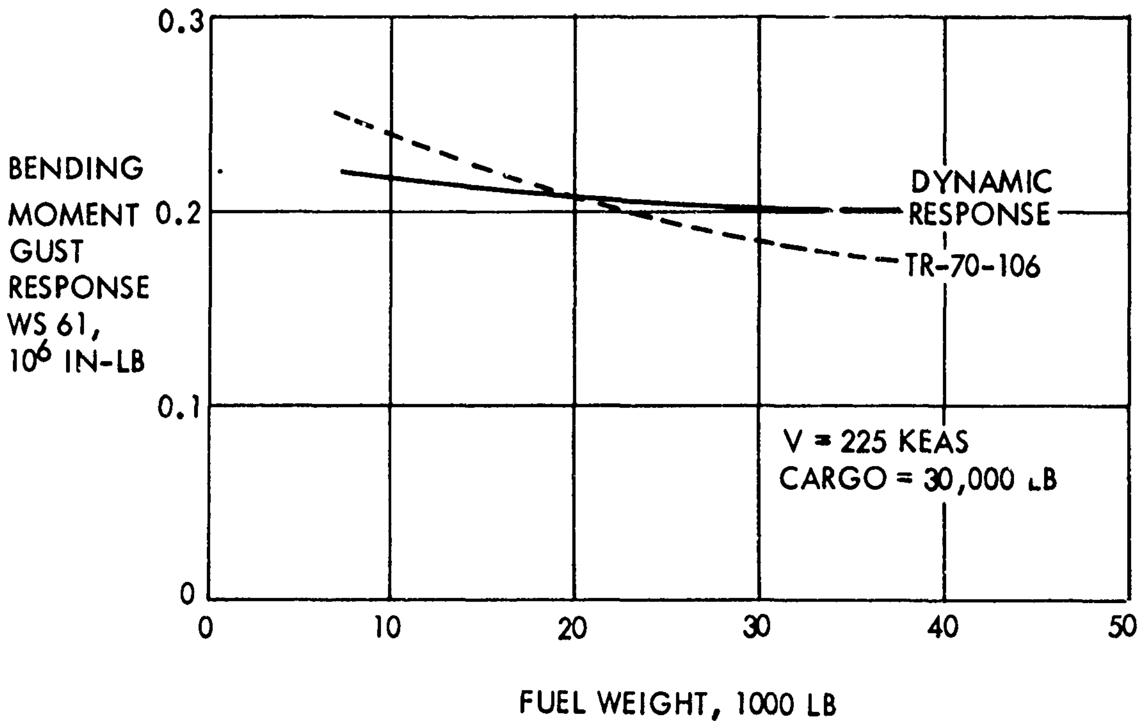


Figure 48 Comparison of rms Bending Response, C-130

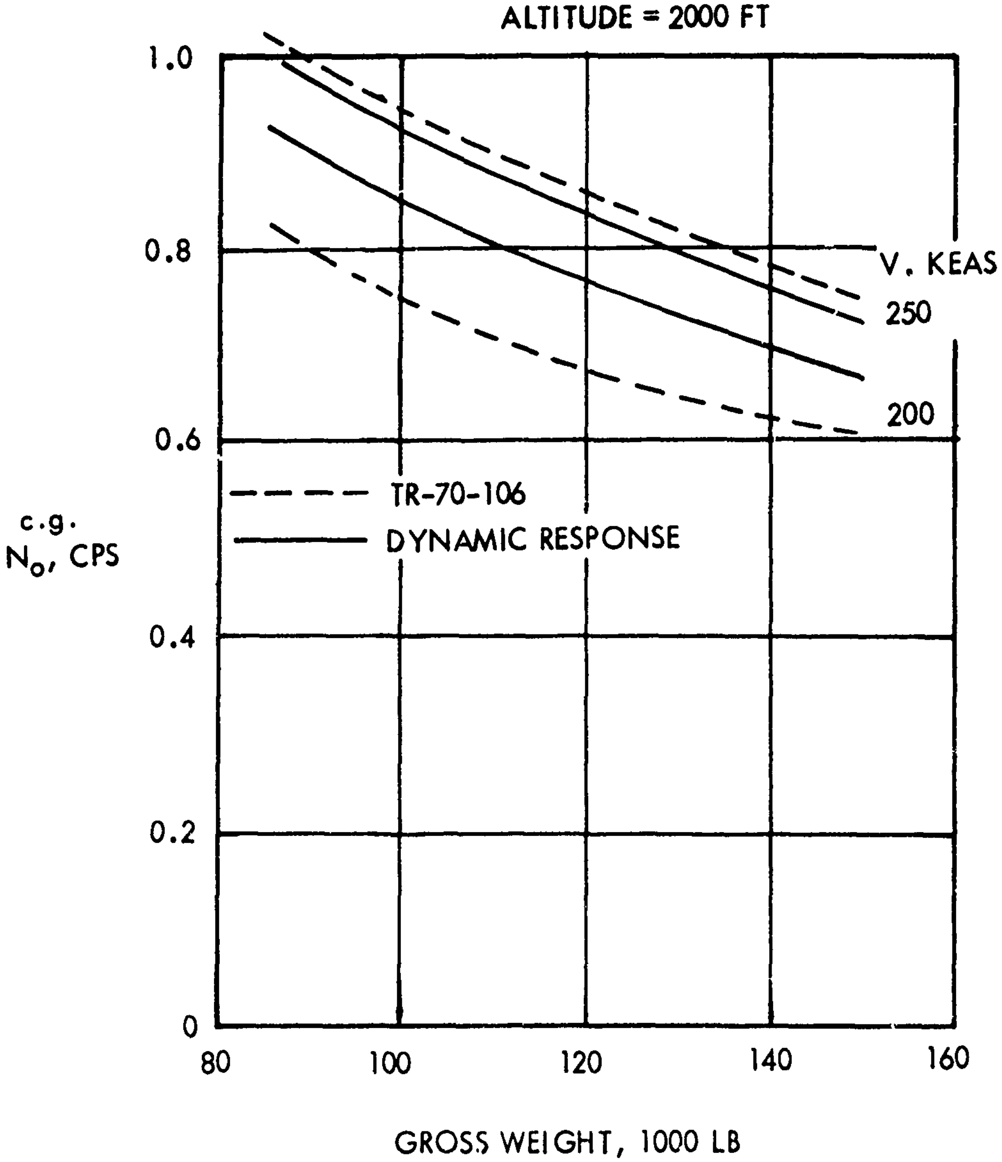


Figure 49 Comparisons of Characteristic Frequencies, N_o, C-130

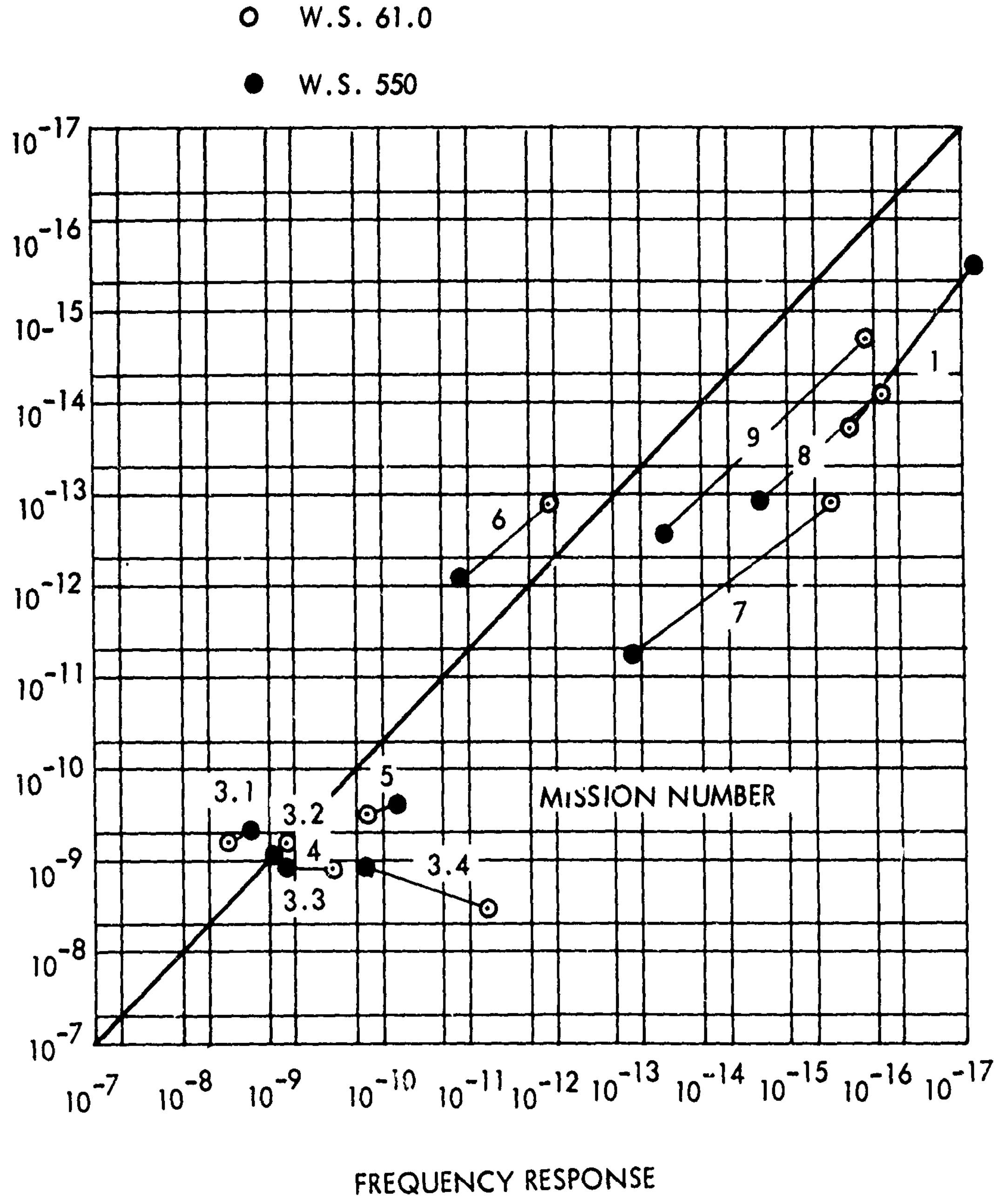


Figure 50 Comparison of Limit Load Exceedance Rate, C-130

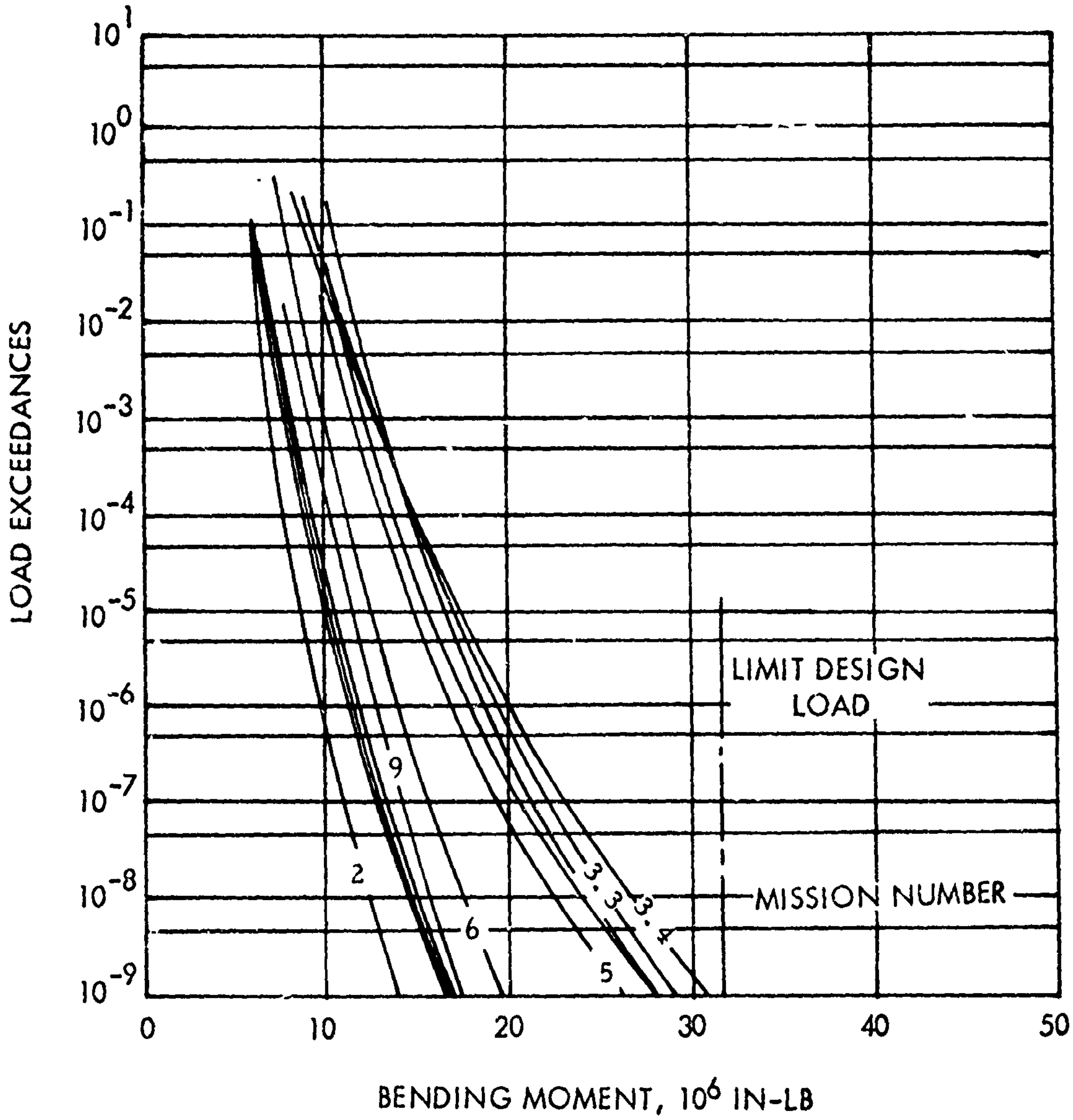


Figure 51 Wing Station 61.0 Moment Exceedance, C-130

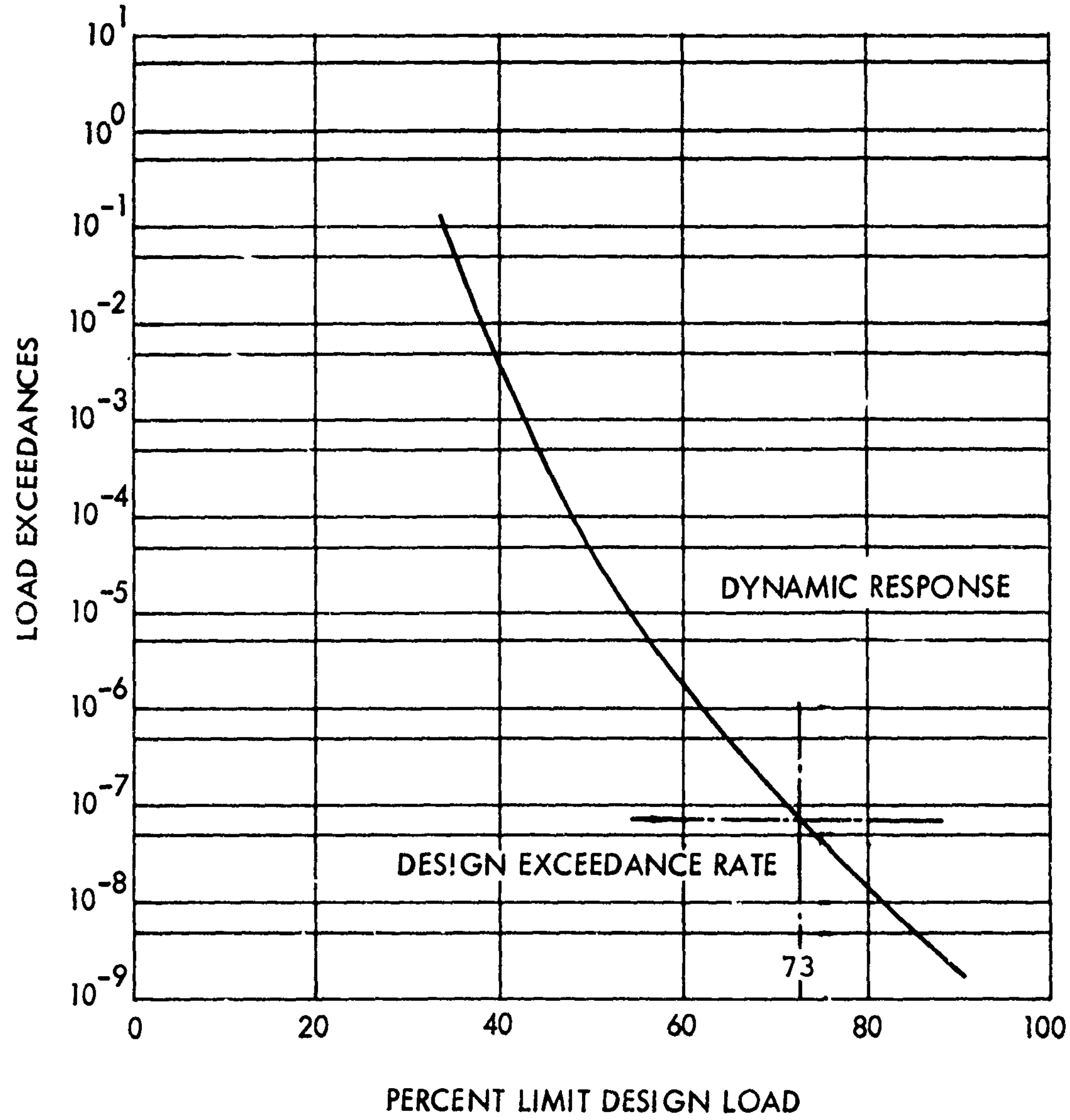


Figure 52 Mission Analysis Design Gust Load W.S. 61, C-130

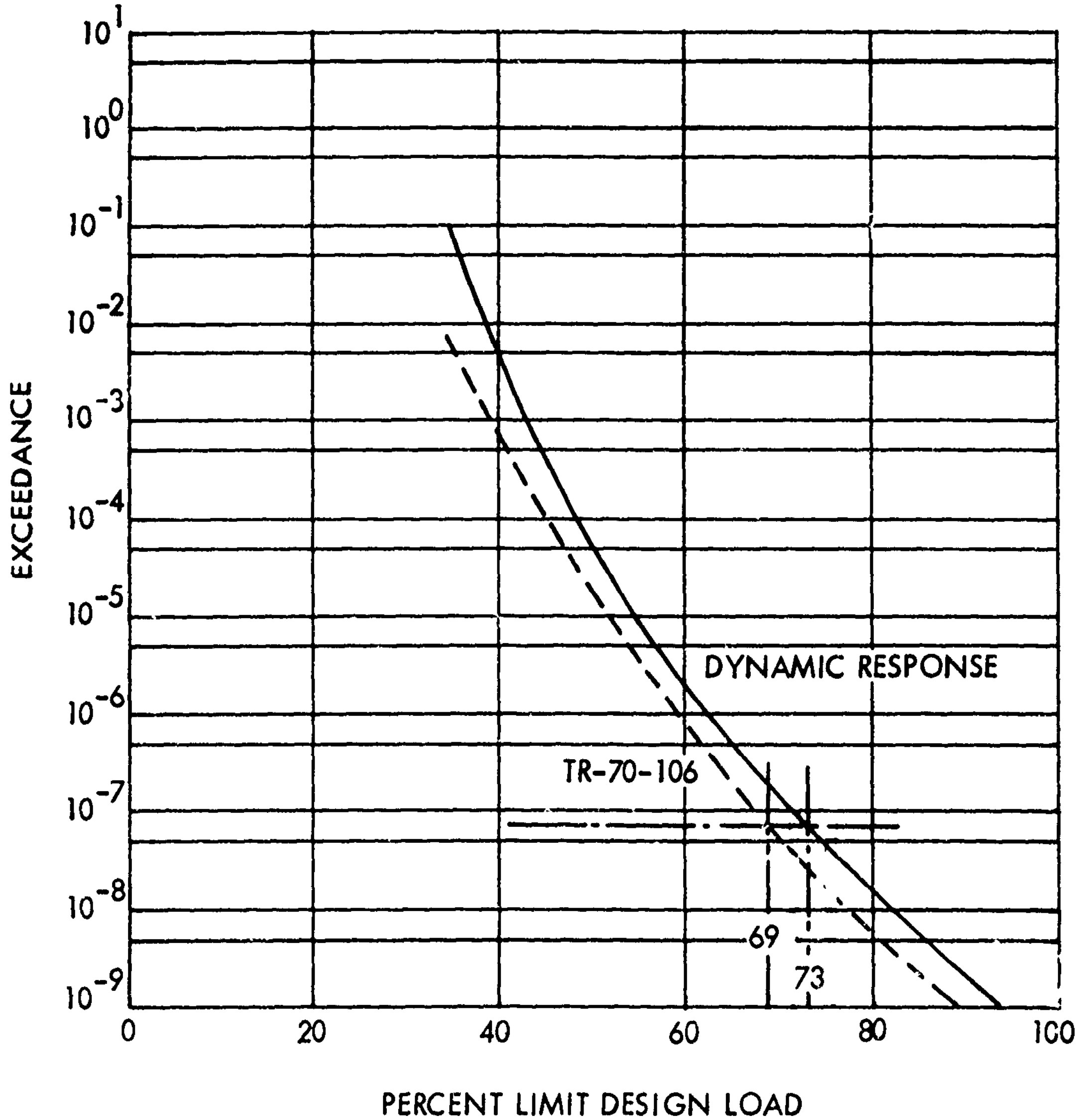


Figure 53 Comparison of Percent Limit Design Load, C-130

SECTION VI

C-140 ANALYSIS RESULTS

Basic Data

The C-140 (JetStar) is the smallest transport evaluated. The operational flight envelope is given on Figure 54. Minimum symmetrical maneuver load factors are +3.0 and -1.0. Gust criteria for the C-140 was the gust loads formula with final substantiation including a discrete transient gust analyses. Elastic lift curve slope and unit bending moments for the C-140 are given on Figures 55 and 56, respectively.

Structural design requirements on the C-140 did not include any mission definitions for fatigue analyses. Therefore, representative missions have been defined for this study and are presented in Figure 57. The missions selected are maximum and half payload for various flight times.

Limit wing design load on the C-140 is a gust condition. The bending moment at the wing root for the critical gust condition is slightly over 4.0×10^6 in. lb. For this evaluation and verification of the gust design manual, maximum bending moment for a +3.0g maneuver was determined. This maneuver design bending moment is 3.34×10^6 in. lb. These values are used to determine if a 3g maneuver design would have been adequate for gusts.

Preliminary Design Approach

Results from the preliminary design approval are presented in Figure 58. The open symbols are those derived using the maximum maneuver limit bending moment. Below altitude of 30,000 feet the maneuver derived load level is inadequate for gusts as it was in the original analyses. Using the actual design limit bending moment for the C-140 results in adequate margins for all altitudes. The proximity of the X/A value at an altitude of 20,000 feet indicates that the design load from the manual is the same as that from the gust loads formula.

Detailed Design Approach

Load exceedances are shown for each of the missions selected. Comparison of the design manual single degree of freedom with dynamic response is not available due to

economic considerations as this study was structured to use existing readily available data.

Figure 59 presents the results of the mission analysis using the load exceedance format. It is apparent that a 3.0g maneuver design load could have been justified. Wing root bending moment of 3.34×10^6 in. lb. for a 3.0g maneuver would result in 2.78×10^6 in. lb. for a 2.5g maneuver as a first approximation. Based on the exceedance data, a 2.5g symmetric maneuver load factor for transports would have been adequate for design.

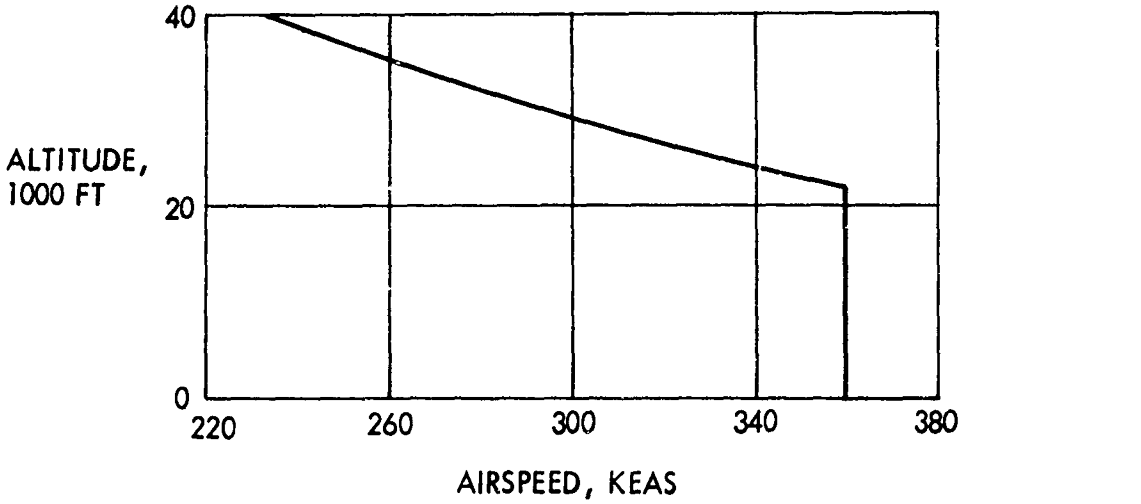


Figure 54 Operational Flight Envelope, C-140

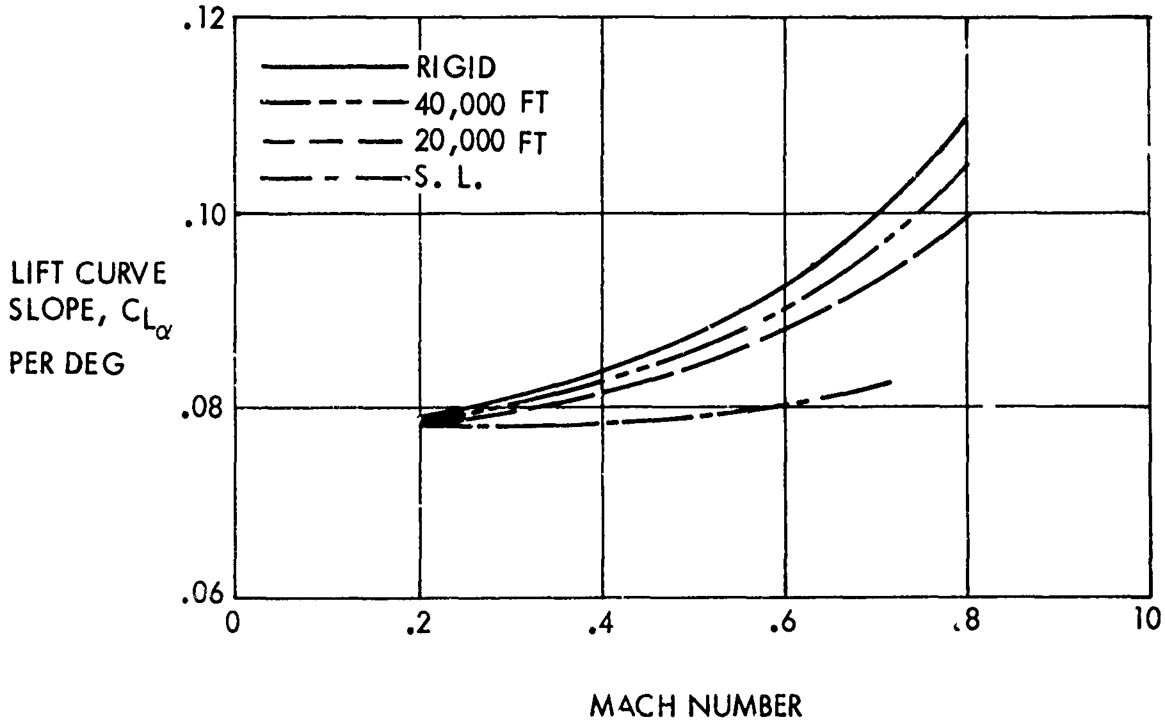
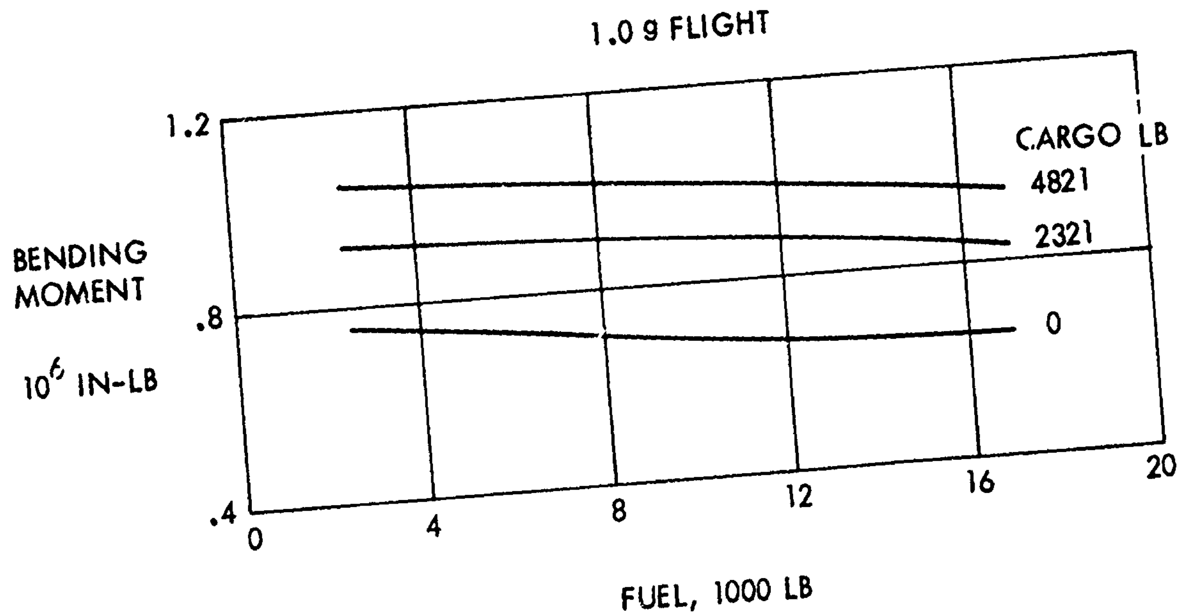


Figure 55 Elastic Lift Curve Slope, C-140



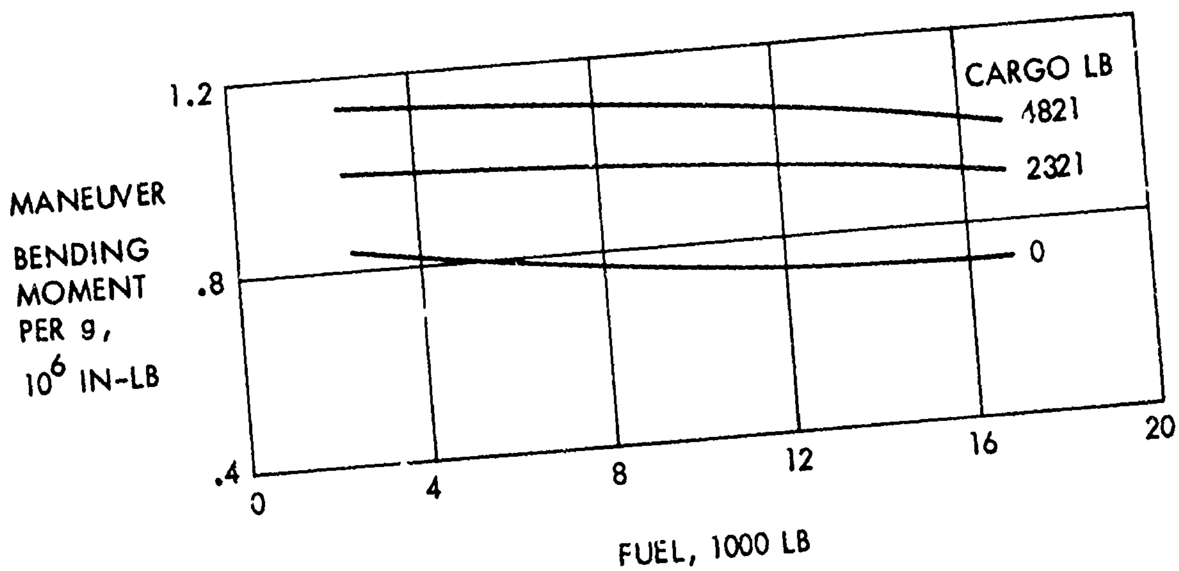


Figure 56 Unit, Bending Moment W.S. 41.5, C-140

C-140 MISSION 1

SEGMENT	1	2	3	4	5	6	
TIME	12	8	108	120	6	12	MINUTES
ALTITUDE	10000	27000	36000	40000	31000	10000	FEET
SPEED	330	290	240	218	280	330	KEAS
GROSS WT	40500	34000	36100	30000	26700	26000	POUNDS
PAYLOAD	4821	4821	4821	4821	4821	4821	POUNDS

C-140 MISSION 2

SEGMENT	1	2	3	4	5	6	
TIME	12	8	54	54	6	12	MINUTES
ALTITUDE	10000	27000	35000	27000	28000	10000	FEET
SPEED	330	290	245	232	290	330	KEAS
GROSS WT	40500	39000	37500	35000	34500	34000	POUNDS
PAYLOAD	4821	4821	4821	4821	4821	4821	POUNDS

C-140 MISSION 3

SEGMENT	1	2	3	4	5	6	
TIME	10	7	60	60	6	12	MINUTES
ALTITUDE	10000	29000	39000	41000	30000	10000	FEET
SPEED	330	250	216	210	275	330	KEAS
GROSS WT	33000	32500	31000	27000	26600	26000	POUNDS
PAYLOAD	4821	4821	4821	4821	4821	4821	POUNDS

C-140 MISSION 4

SEGMENT	1	2	3	4	5	6	
TIME	12	8	108	120	6	12	MINUTES
ALTITUDE	10000	27000	36000	40000	31000	10000	FEET
SPEED	330	290	240	218	280	330	KEAS
GROSS WT	38000	36500	30600	27500	24200	23500	POUNDS
PAYLOAD	2321	2321	2321	2321	2321	2321	POUNDS

Figure 57 Mission Profiles, C-140

C-140 MISSION 5

SEGMENT	1	2	3	4	5	6	
TIME	12	8	54	54	6	12	MINUTES
ALTITUDE	10000	27000	35000	37000	28000	10000	FEET
SPEED	330	290	245	232	290	350	KEAS
GROSS WT	38000	36500	35000	32500	32000	31500	POUNDS
PAYLOAD	2321	2321	2321	2321	2321	2321	POUNDS

C-140 MISSION 6

SEGMENT	1	2	3	4	5	6	
TIME	10	7	60	60	6	12	MINUTES
ALTITUDE	10000	29000	39000	41000	30000	10000	FEET
SPEED	330	250	216	210	275	330	KEAS
GROSS WT	30500	30000	28500	25500	24100	23500	POUNDS
PAYLOAD	2321	2321	2321	2321	2321	2321	POUNDS

Figure 57 Mission Profiles, C-140 (Continued)

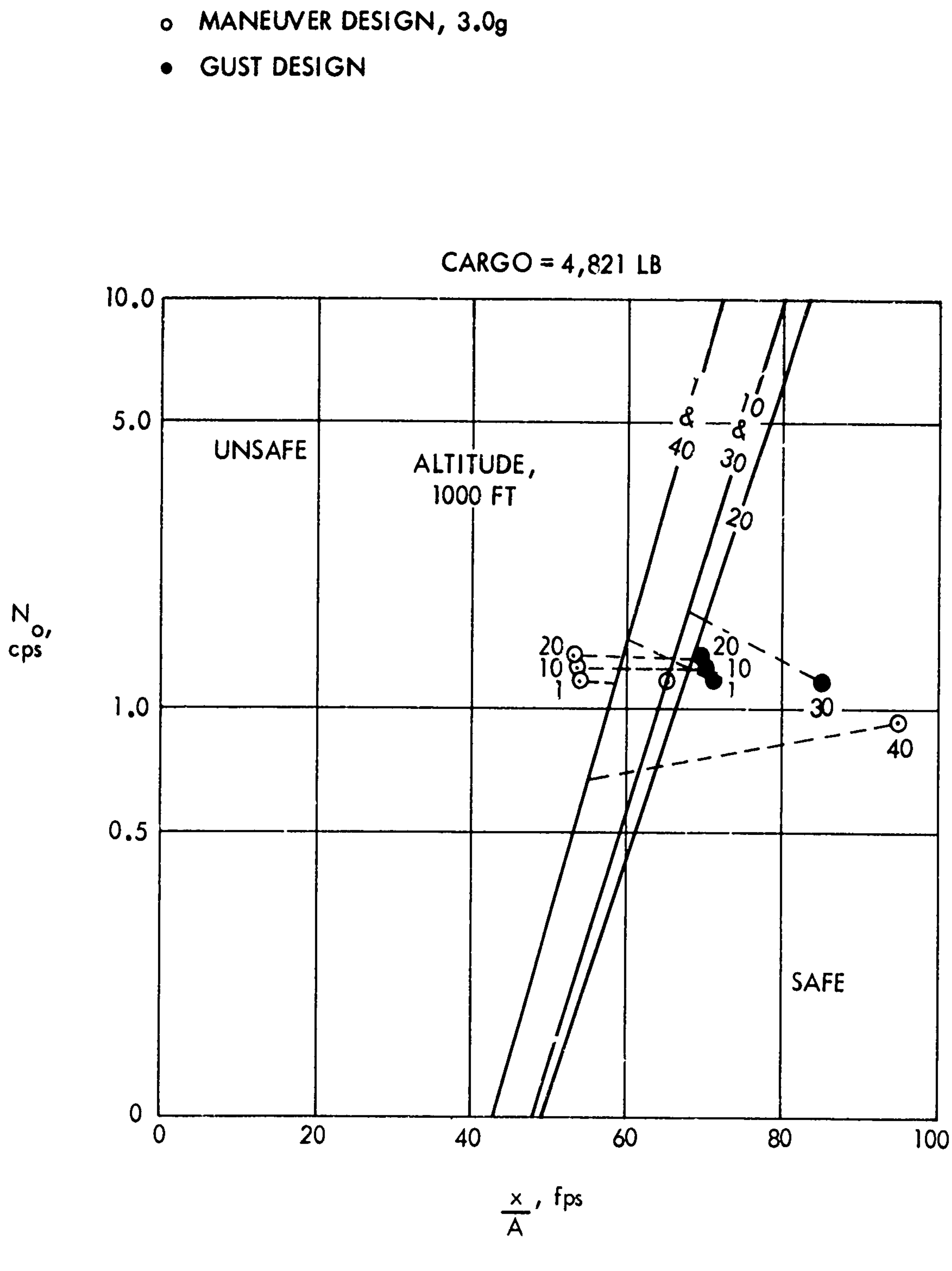


Figure 58 Preliminary (Perhaps Final) Design, C-140

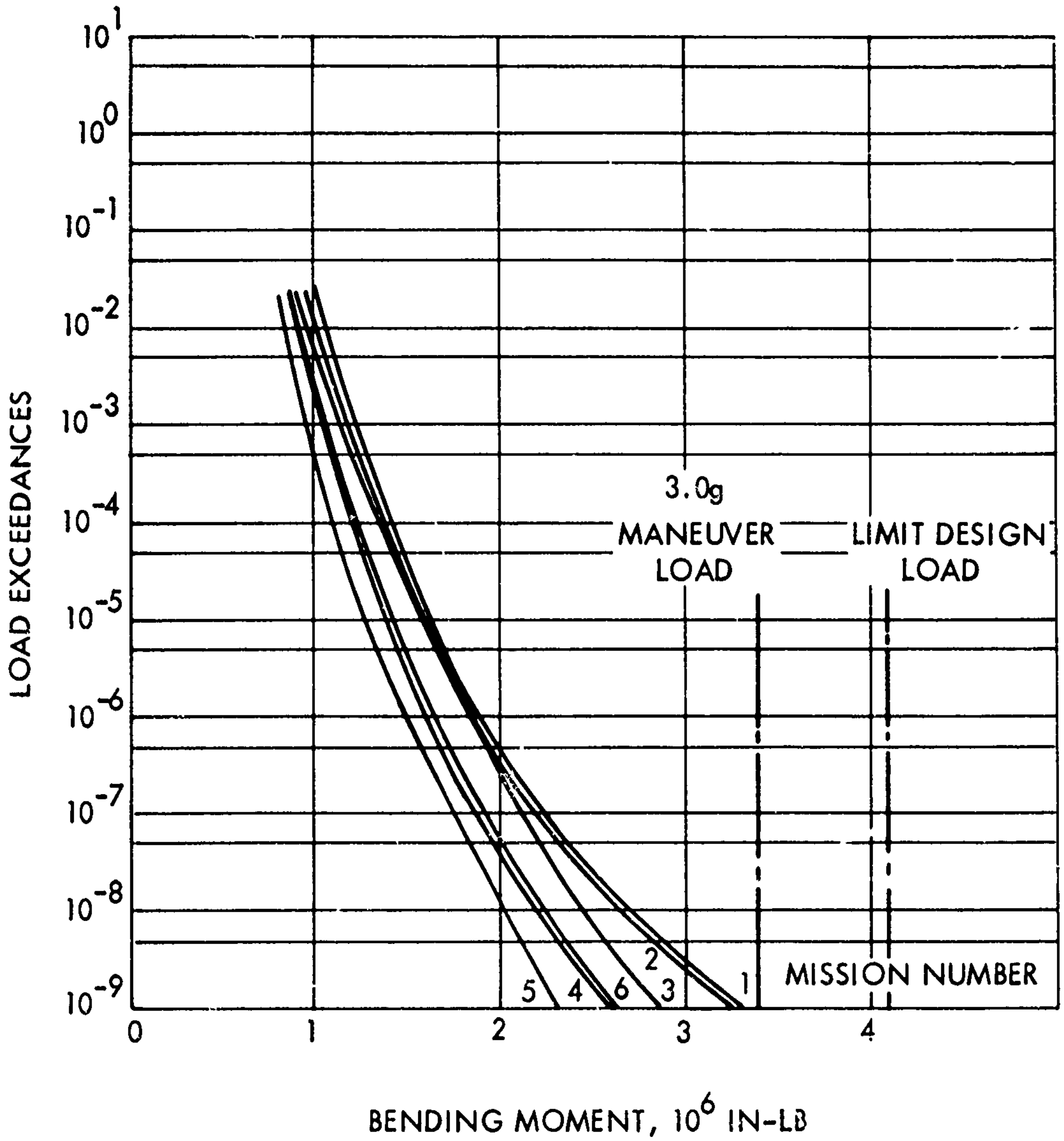


Figure 59 Wing Station 41.5 Moment Exceedance, C-140

SECTION VII

C-5A ANALYSIS RESULTS

Basic Data

Operational flight envelope for the C-5A is given on Figure 60. The symmetrical maneuver design load factor is +2.5 to -1.0 for cargo weights up to 220,000 pounds. An additional overload gross weight at a positive load factor of 2.25 was also part of the C-5A design.

Gust criteria for the C-5A included power spectral techniques and what has been defined as a rational probability analysis (RPA). The RPA analysis is very similar to the exceedance design approach in the design manual. The primary difference is the exceedance rate at which the load is determined and the interpretation put on the load. A failure rate of .0005 or a probability of survival of .9995 for fleet lifetime is interpreted as an ultimate load or survival of gust encounter.

Other differences include spectrum $\Phi(\Omega)/\sigma^2 = 0.8L/(1 + \Omega L)^{1.8}$, scale of turbulence of 2500 and significant difference in turbulence parameters. In addition, considerable effort was expended in description of the environment for contour flying. In terms of criticalness, the contour gust requirements dominated C-5A design. Lateral gusts also had a significant effect on the C-5A design.

Mission descriptions are given in Figure 61. Each mission is condensed to six segments. In the design, Missions 2, 13, and 14 include the contour flying. Contour statistics are not included in this effort. The remaining data required to do the various design approaches are the elastic lift curve slope (Figure 62) and the unit loads (Figures 63, 64, and 65).

Preliminary Design Approach

Results from the other three study aircraft and relative similarity of unit loads as a function of cargo and fuel leads to the conclusion that the cargo for the 2.25g limitation will be gust critical. Results from the preliminary design approach are presented on Figures 66 and 67. At maximum cargo weight of 265,000 pounds for all altitudes and for both wing stations, the C-5A has generous margins. The primary reason for this is the fact that lift curve slopes are similar; speed schedules are

similar but the mass parameter due to higher wing loadings is higher. The net result is less gust loading sensitivity. Two missions, both at light weight, show unsafe in the composite load factor chart. As noted in the summary of results, load, not load factor, is a better comparison. These missions are not critical from a load or stress evaluation.

Detailed Design Approach

Comparison of r.m.s. center of gravity acceleration is presented on Figure 68. The acceleration from dynamic gust response is roughly 15% higher than the single degree of freedom method in the design manual. Wing root bending r.m.s. response is shown on Figure 69 and they compare well. Structural flexibility effects are evident from the comparison of r.m.s. response at Station 920 (70% span) and the value of zero crossing number being a factor of 2.3 times higher as shown on Figure 71. The dynamic response data for the C-5A comparison are analytical (not flight test correlated as used on the C-130 and C-141A) and are from the design release gust analysis. The single degree of freedom method provides a good estimate of the C-5A analytical gust response. The C-5A frequency response indicates a higher level of structural response. Consistent with past aircraft development, flight test dynamic response will become available. A favorable correlation is expected.

Mission exceedance rates at limit load are shown on Figure 72. Missions not shown are off scale on the safe side. In general, the design manual results in conservative values in the wing root area and unconservative in the outer span area. All missions result in loads significantly less than maneuver design values. Load exceedance curves for all of the missions are shown on Figure 73. Composite load exceedances are presented on Figure 74 for Station 120 and on Figure 75 for Station 920.

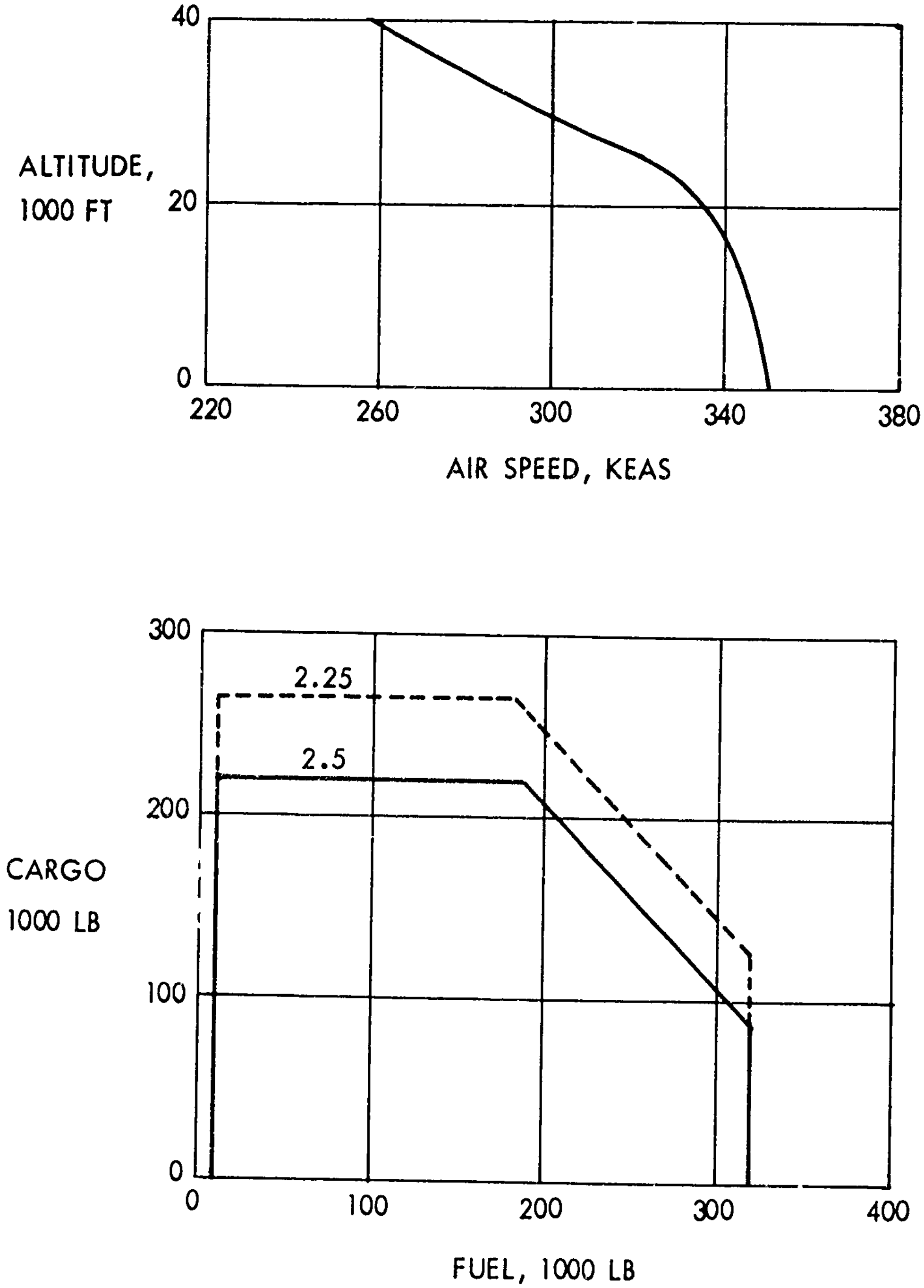


Figure 30 Operational Flight Envelope, C-5A

C-5A MISSION 1

SEGMENT	1	2	3	4	5	6	
TIME	7	10	38	37	2	3	MINUTES
ALTITUDE	10000	27500	35000	35000	27500	10000	FEET
SPEED	234	248	195	195	212	225	KEAS
GROSS WT	449000	444000	434000	423000	422000	421000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - .051

C-5A MISSION 2

SEGMENT	1	2	3	4	5	6	
TIME	1	11	21	21	11	1	MINUTES
ALTITUDE	1000	1000	300	300	1000	1000	FEET
SPEED	300	350	350	350	350	350	KEAS
GROSS WT	425000	420000	411000	382000	377000	377000	POUNDS
CARGO WT	20000	20000	20000	20000	20000	20000	POUNDS

UTILIZATION - .023

C-5A MISSION 3

SEGMENT	1	2	3	4	5	6	
TIME	3	8	43	43	8	3	MINUTES
ALTITUDE	1000	1000	300	300	1000	1000	FEET
SPEED	300	350	350	350	350	150	KEAS
GROSS WT	418000	416000	396000	375000	372000	372000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - .061

C-5A MISSION 4

SEGMENT	1	2	3	4	5	6	
TIME	8	24	131	131	2	3	MINUTES
ALTITUDE	9000	27000	37000	37000	30000	10000	FEET
SPEED	262	242	235	235	256	258	KEAS
GROSS WT	572000	562000	523000	486000	480000	480000	POUNDS
CARGO WT	50000	50000	50000	50000	50000	50000	POUNDS

UTILIZATION - .027

Figure 61 Design Mission Profiles, C-5A

C-5A MISSION 5

SEGMENT	1	2	3	4	5	6	
TIME	5	21	19	2	3	10	MINUTES
ALTITUDE	10000	33000	40000	33000	10000	1000	FEET
SPEED	258	214	210	253	190	150	KEAS
GROSS WT	369000	362000	358000	358000	358000	350000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - .005

C-5A MISSION 6

SEGMENT	1	2	3	4	5	6	
TIME	9	25	240	356	2	3	MINUTES
ALTITUDE	7500	22500	33000	35000	30000	10000	FEET
SPEED	268	251	258	244	257	241	KEAS
GROSS WT	690000	679000	588000	509000	475000	474000	POUNDS
CARGO WT	90000	90000	90000	90000	90000	90000	POUNDS

UTILIZATION - .185

C-5A MISSION 7

SEGMENT	1	2	3	4	5	6	
TIME	9	25	120	168	2	4	MINUTES
ALTITUDE	7500	22500	32000	34000	27000	10000	FEET
SPEED	274	250	258	250	271	220	KEAS
GROSS WT	698000	687000	639000	578000	578000	577000	POUNDS
CARGO WT	190000	190000	190000	190000	190000	190000	POUNDS

UTILIZATION - .10

C-5A MISSION 8

SEGMENT	1	2	3	4	5	6	
TIME	11	22	92	2	4	10	MINUTES
ALTITUDE	10000	27000	34000	35000	27500	10000	FEET
SPEED	262	241	249	216	173	129	KEAS
GROSS WT	610000	600000	568000	568000	568000	561000	POUNDS
CARGO WT	200000	200000	200000	200000	200000	200000	POUNDS

UTILIZATION - .092

Figure 61 Design Mission Profiles, C-5A (Cont'd)

C-5A MISSION 9

SEGMENT	1	2	3	4	5	6	
TIME	8	23	120	52	3	3	MINUTES
ALTITUDE	10000	20000	38000	40000	30000	10000	FEET
SPEED	245	276	230	219	184	285	KEAS
GROSS WT	523000	514000	478000	463000	463000	463000	POUNDS
CARGO WT	100000	100000	100000	100000	100000	100000	POUNDS

UTILIZATION - .173

C-5A MISSION 10

SEGMENT	1	2	3	4	5	6	
TIME	8	25	240	194	2	3	MINUTES
ALTITUDE	8000	24000	35000	37000	30000	10000	FEET
SPEED	265	252	240	229	266	250	KEAS
GROSS WT	626000	616000	534000	475000	475000	475000	POUNDS
CARGO WT	25000	25000	25000	25000	25000	25000	POUNDS

UTILIZATION - .010

C-5A MISSION 11

SEGMENT	1	2	3	4	5	6	
TIME	8	25	240	194	2	3	MINUTES
ALTITUDE	8000	24000	36000	38000	28000	10000	FEET
SPEED	265	252	240	229	266	258	KEAS
GROSS WT	626000	616000	534000	475000	475000	475000	POUNDS
CARGO WT	90000	90000	90000	90000	90000	90000	POUNDS

UTILIZATION - .034

C-5A MISSION 12

SEGMENT	1	2	3	4	5	6	
TIME	8	25	240	194	2	3	MINUTES
ALTITUDE	8000	24000	36000	38000	28000	10000	FEET
SPEED	265	252	240	229	266	258	KEAS
GROSS WT	626000	616000	534000	475000	475000	475000	POUNDS
CARGO WT	100000	100000	100000	100000	100000	100000	POUNDS

UTILIZATION - .024

Figure 61 Design Mission Profiles, C-5A (Cont'd)

C-5A MISSION 13.1

SEGMENT	1	2	3	4	5	6	
TIME	9	25	360	276	2	3	MINUTES
ALTITUDE	7500	22500	34000	39000	30000	10000	FEET
SPEED	268	252	250	223	257	257	KEAS
GROSS WT	691000	680000	549000	464000	464000	464000	POUNDS
CARGO WT	95000	95000	95000	95000	95000	95000	POUNDS

UTILIZATION - 0.03

C-5A MISSION 13.2

SEGMENT	1	2	3	4	5	6	
TIME	7	23	65	214	53	7	MINUTES
ALTITUDE	10000	30000	37500	36000	500	10000	FEET
SPEED	262	226	222	240	350	300	KEAS
GROSS WT	485000	477000	458000	517000	494000	493000	POUNDS
CARGO WT	95000	95000	95000	95000	95000	95000	POUNDS

UTILIZATION - 0.03

C-5A MISSION 13.3

SEGMENT	1	2	3	4	5	6	
TIME	49	25	55	13	240	5	MINUTES
ALTITUDE	500	22500	40000	40000	40000	20000	FEET
SPEED	350	263	210	210	210	244	KEAS
GROSS WT	365000	355000	348000	429000	370000	370000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.03

C-5A MISSION 13.4

SEGMENT	1	2	3	4	5	6	
TIME	27	121	413	360	55	4	MINUTES
ALTITUDE	22000	40000	36000	40000	40000	22000	FEET
SPEED	266	220	240	210	210	264	KEAS
GROSS WT	378000	351000	480000	415000	374000	373000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - 0.03

Figure 61 Design Mission Profiles, C-5A (Cont'd)

C-5A MISSION 14

SEGMENT	1	2	3	4	5	6	
TIME	33	139	39	27	105	4	MINUTES
ALTITUDE	11000	36000	500	15000	40000	22000	FEET
SPEED	309	240	350	300	202	232	KEAS
GROSS WT	573000	527000	510000	392000	368000	367000	POUNDS
CARGO WT	95000	95000	95000	0	0	0	POUNDS

UTILIZATION - .058

C-5A MISSION 15

SEGMENT	1	2	3	4	5	6	
TIME	6	21	56	4	3	10	MINUTES
ALTITUDE	10000	31000	40000	31000	10000	1000	FEET
SPEED	231	227	202	178	207	150	KEAS
GROSS WT	396000	389000	376000	376000	376000	368000	POUNDS
CARGO WT	0	0	0	0	0	0	POUNDS

UTILIZATION - .036

MISSION

1 Local Transition
2 Training
3 Low Level Training
4 Training
5 Flight Test
6 Long Range Logistics
7 Short Range Logistics
8 SAAM Short Range

MISSION

9 SAAM Medium Range
10 SAAM Long Range
11 SAAM Long Range
12 SAAM Long Range
13 Joint Exercises
14 Joint Exercises
15 Miscellaneous

Figure 61 Design Mission Profiles, C-5A (Cont'd)

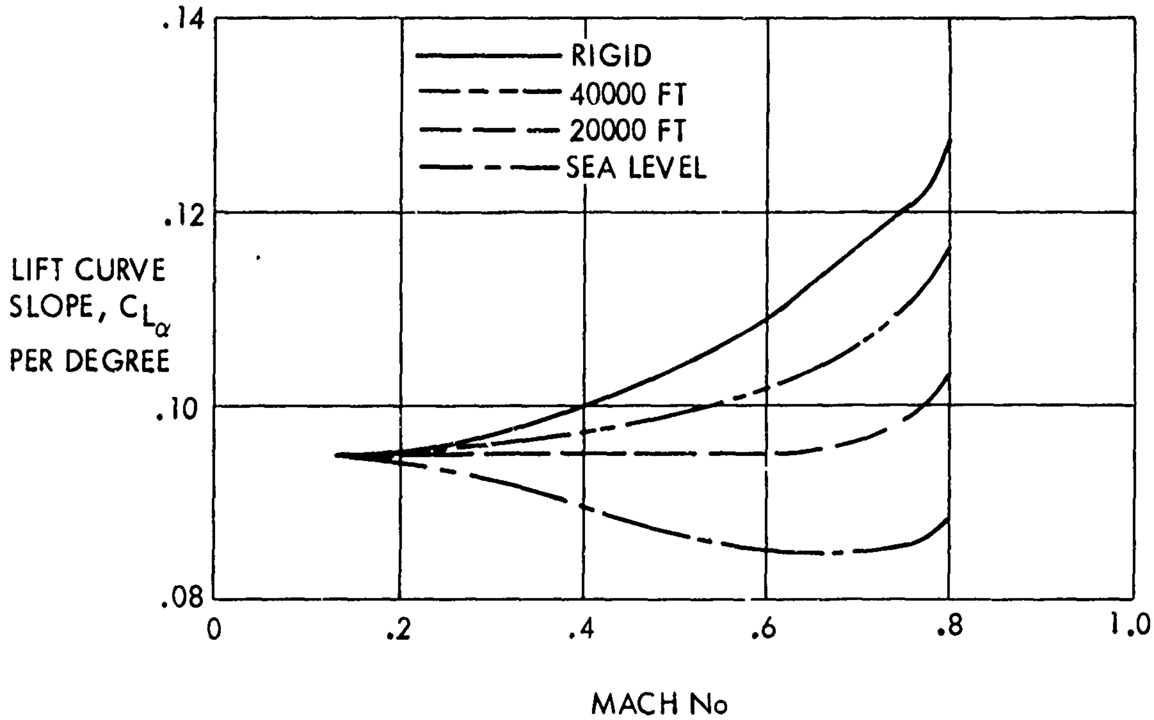
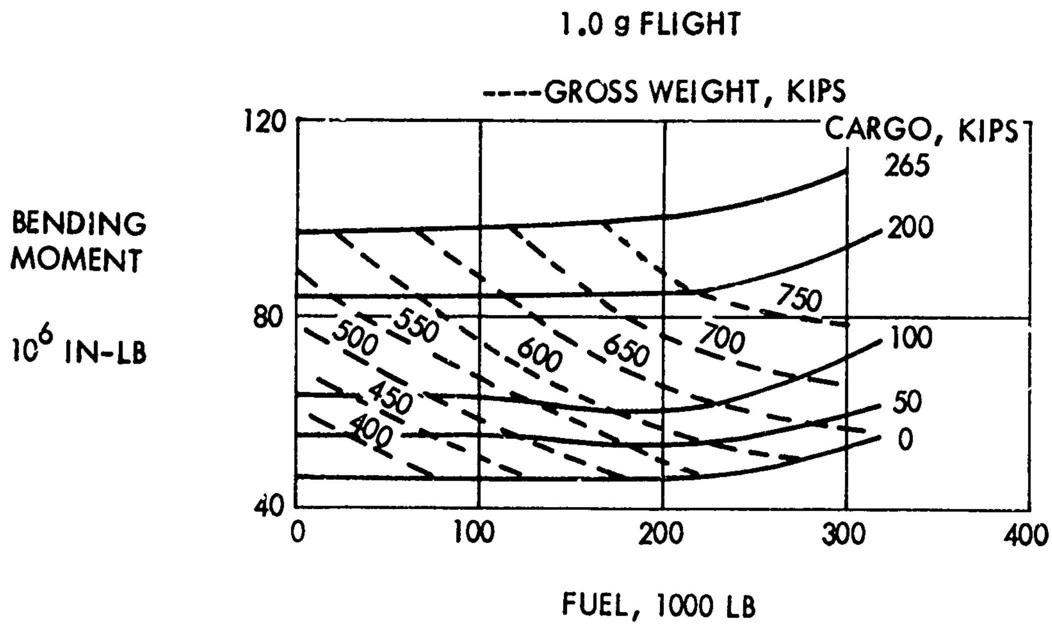


Figure 62 Elastic Lift Curve Slope, C-5A



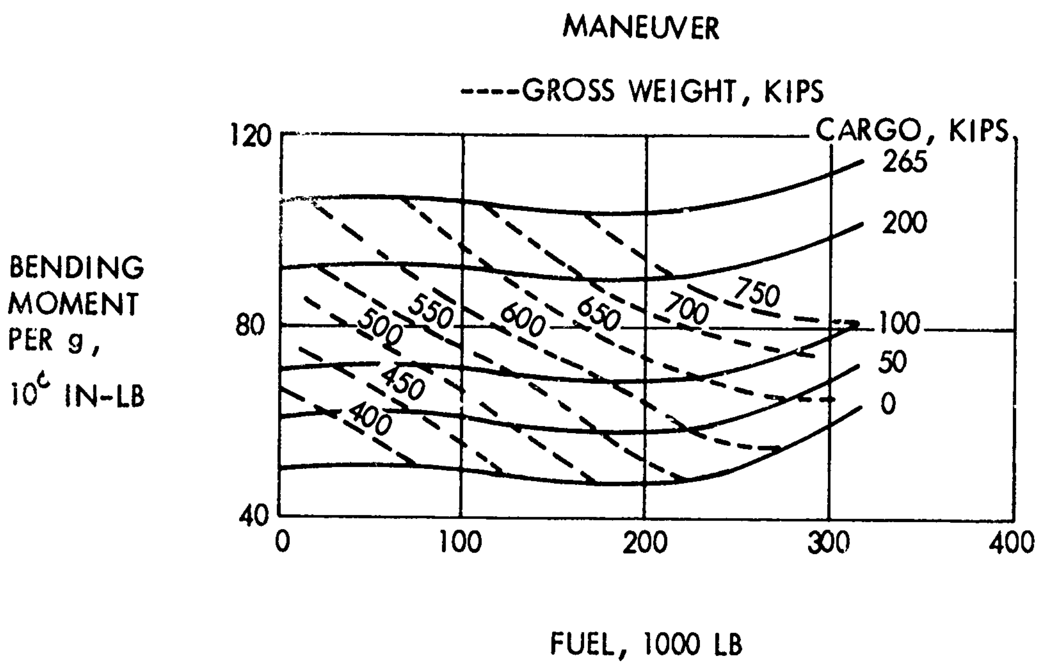


Figure 63 Unit Bending Moment, W.S. 120, C-5A

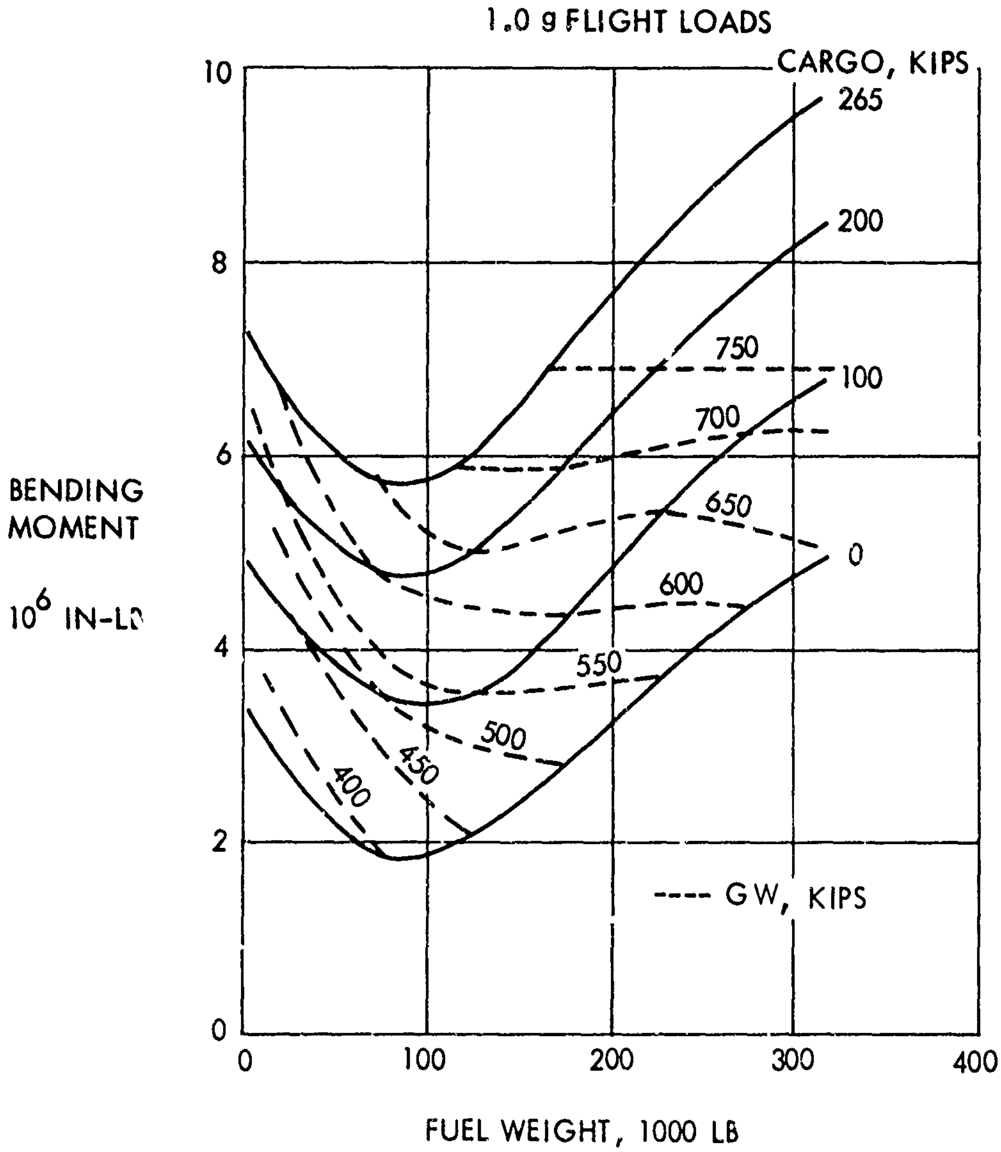


Figure 64 Unit 1.0g Flight Bending Moment, W.S. 920, C-5A

MANEUVER

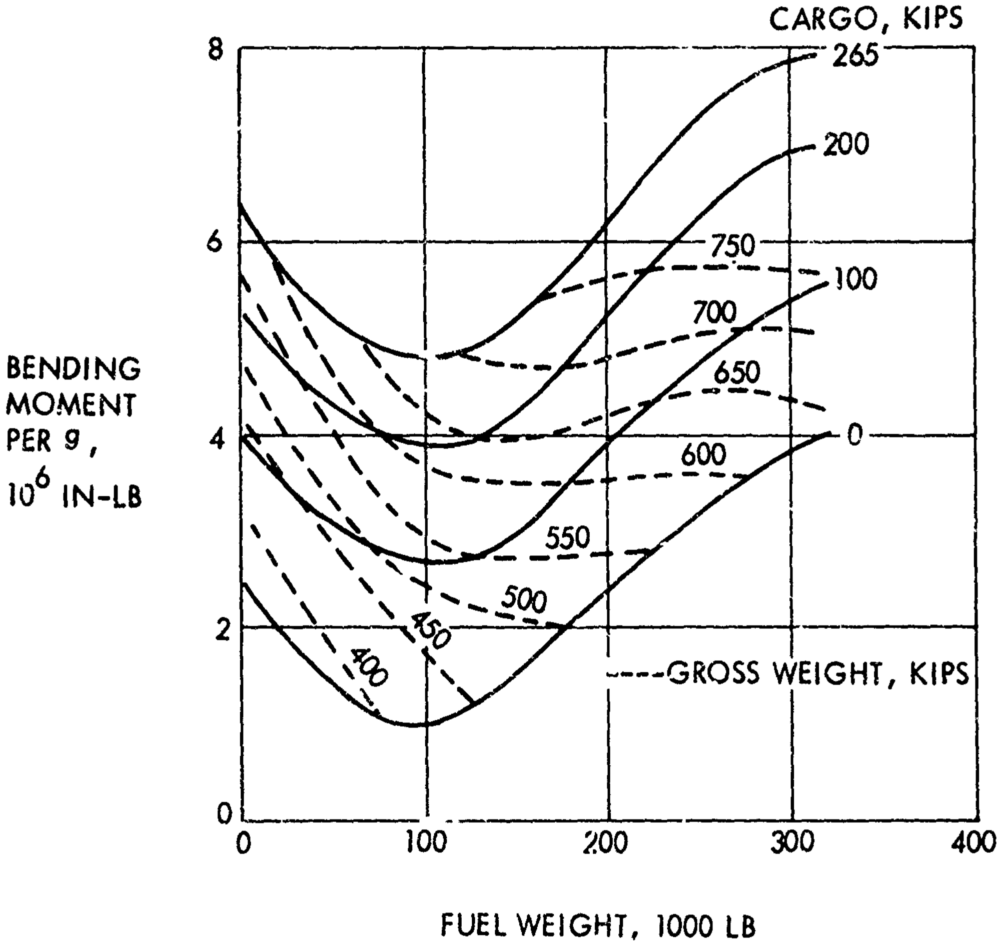


Figure 65 Unit Maneuver Bending Moment, W.S. 920, C-5A

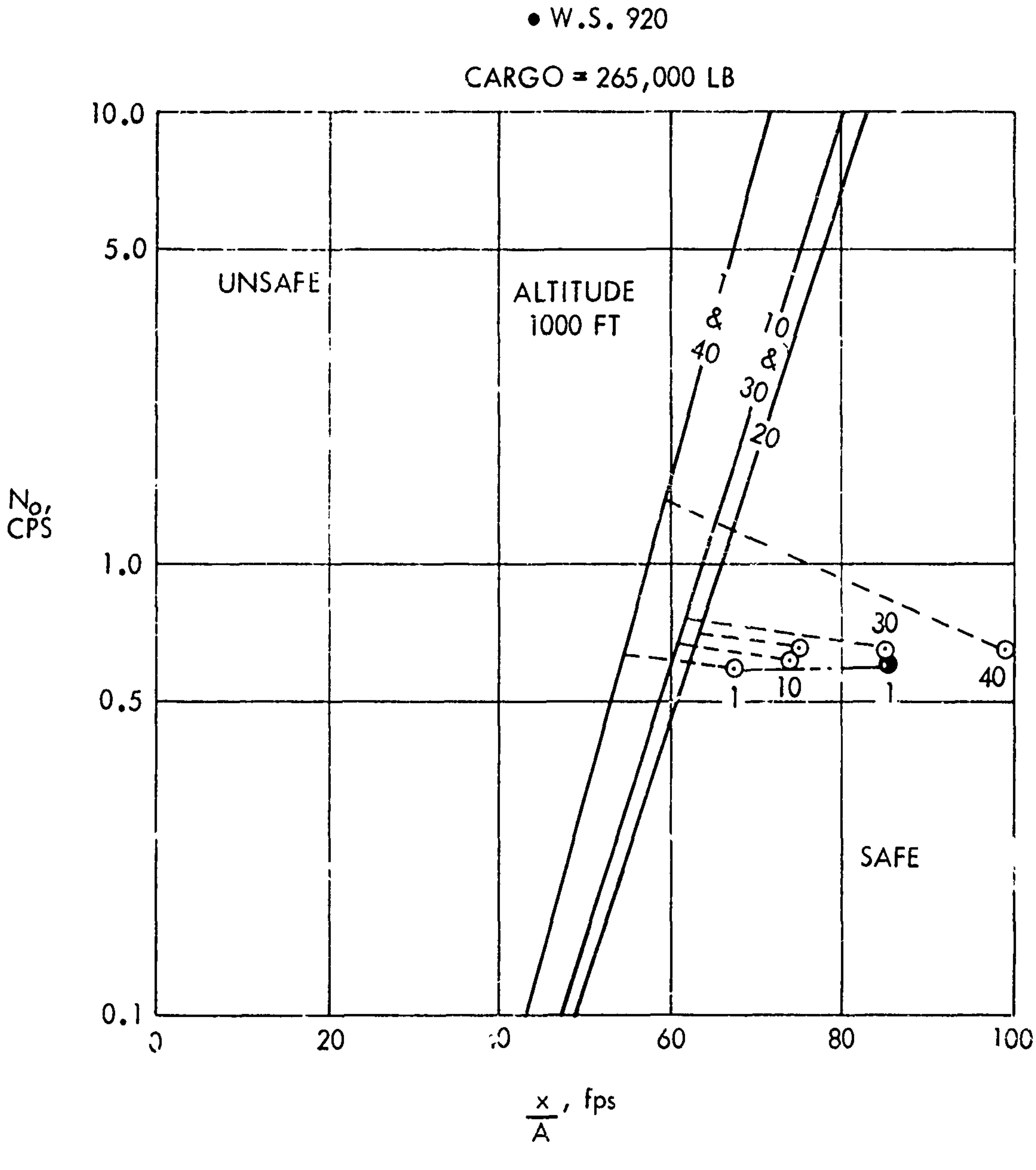


Figure 66 Preliminary (Perhaps Final) Design, C-5A

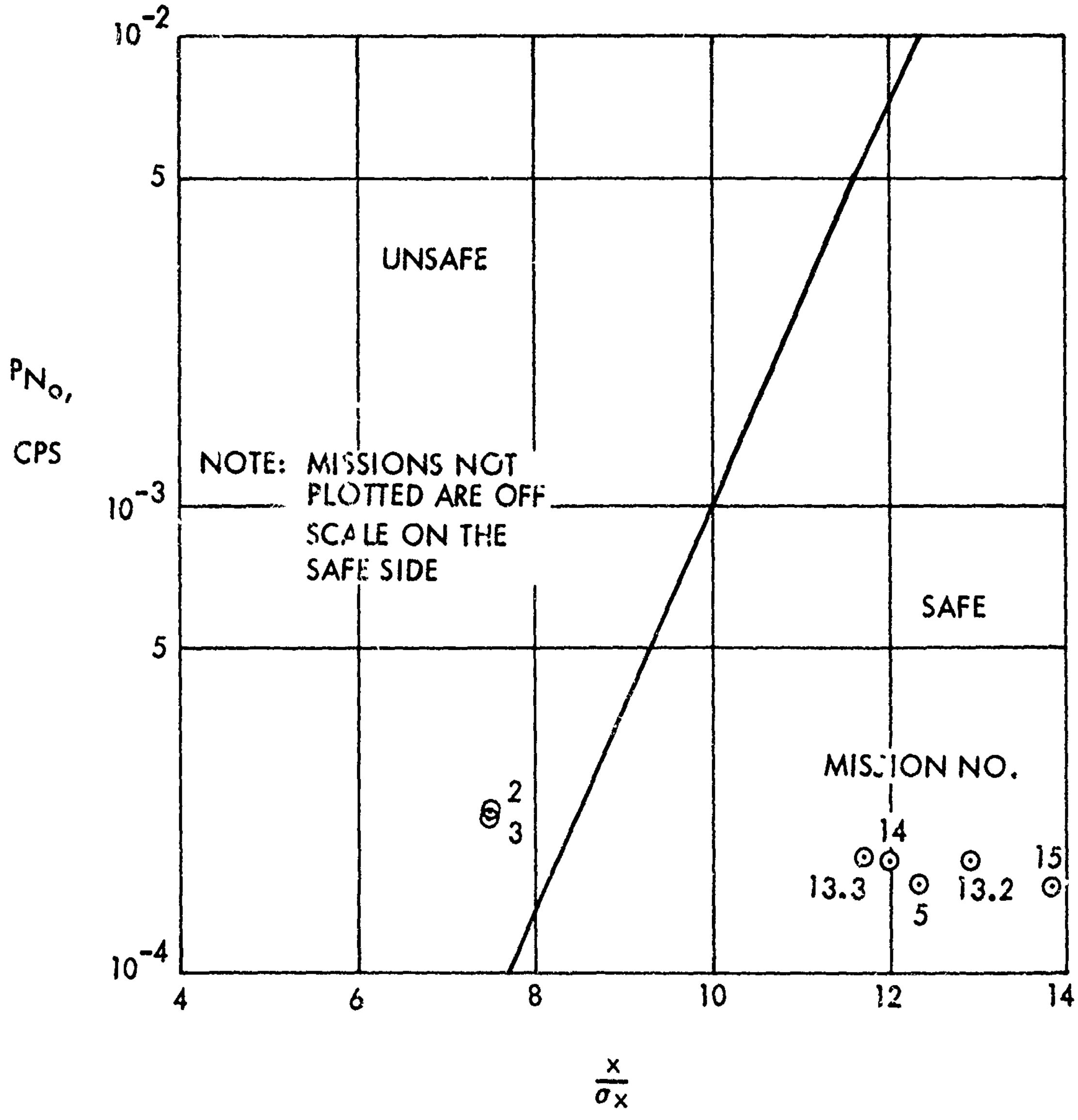


Figure 67 Composite Load Factor Design, C-5A

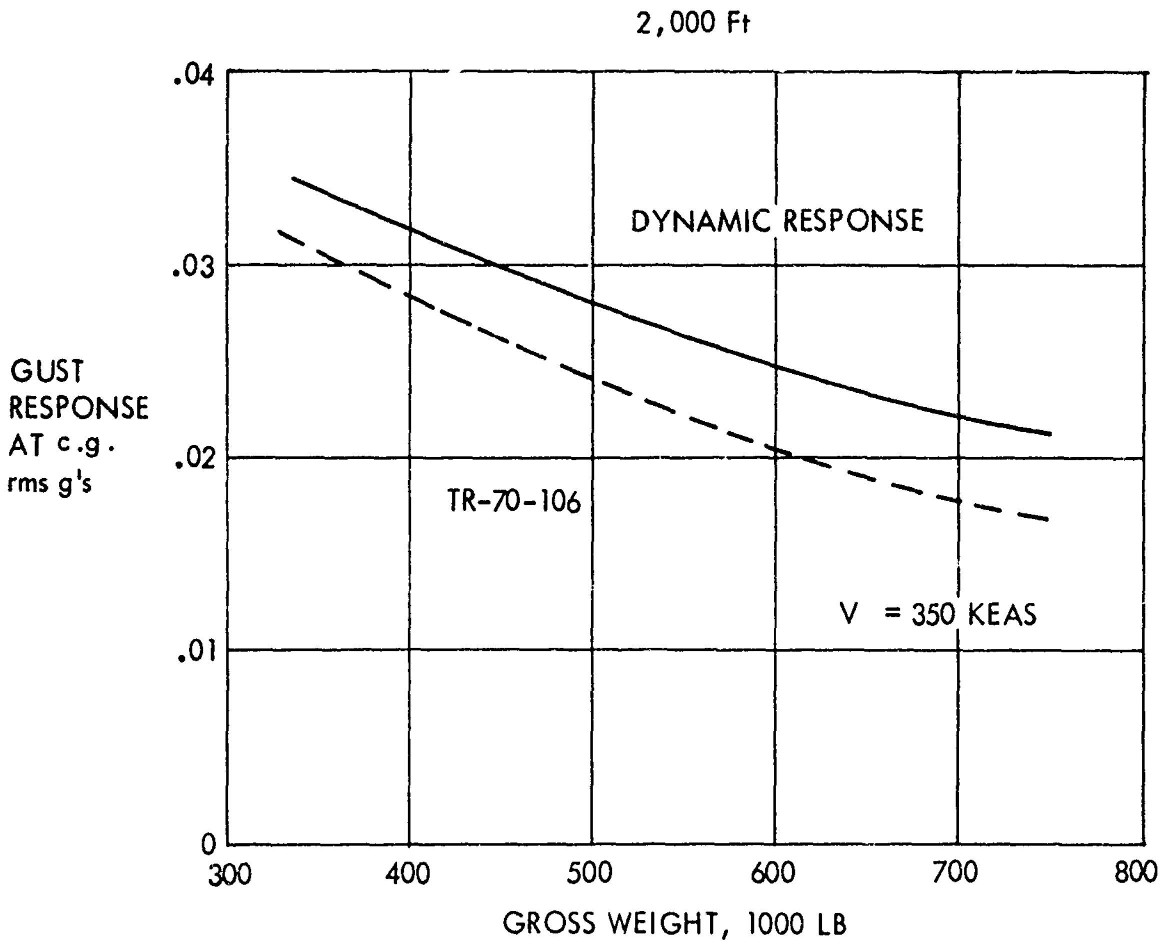


Figure 68 Comparison of rms c.g. Response, C-5A

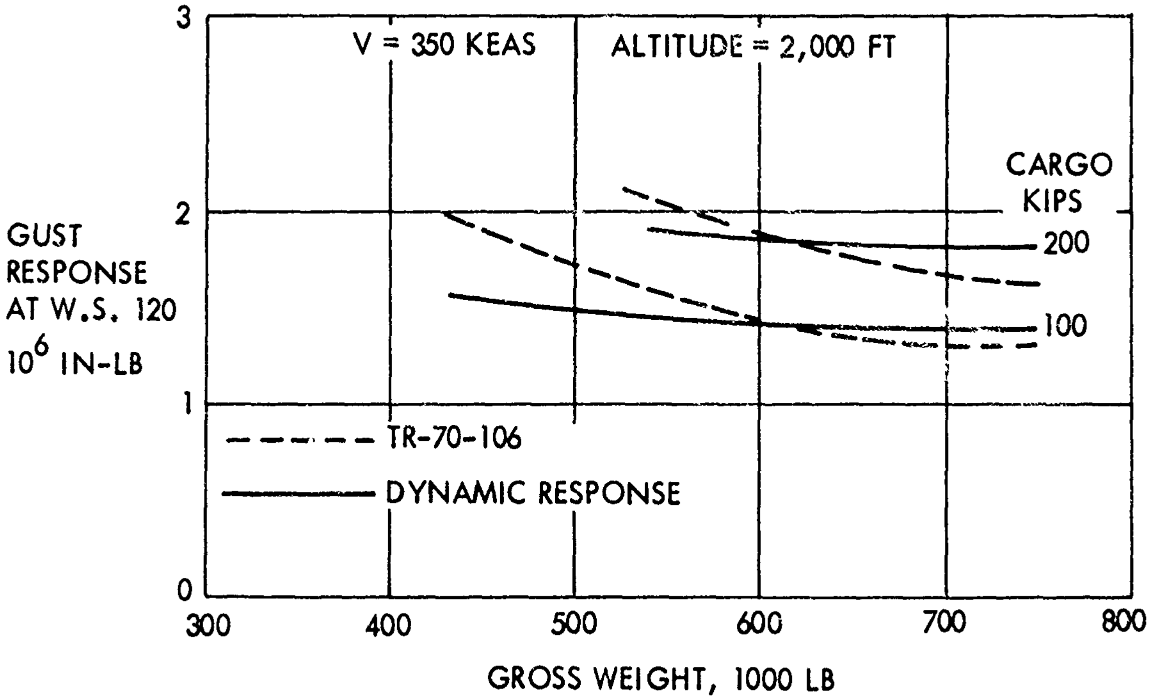


Figure 69 Comparison of rms W.S. 120 Response, C-5A

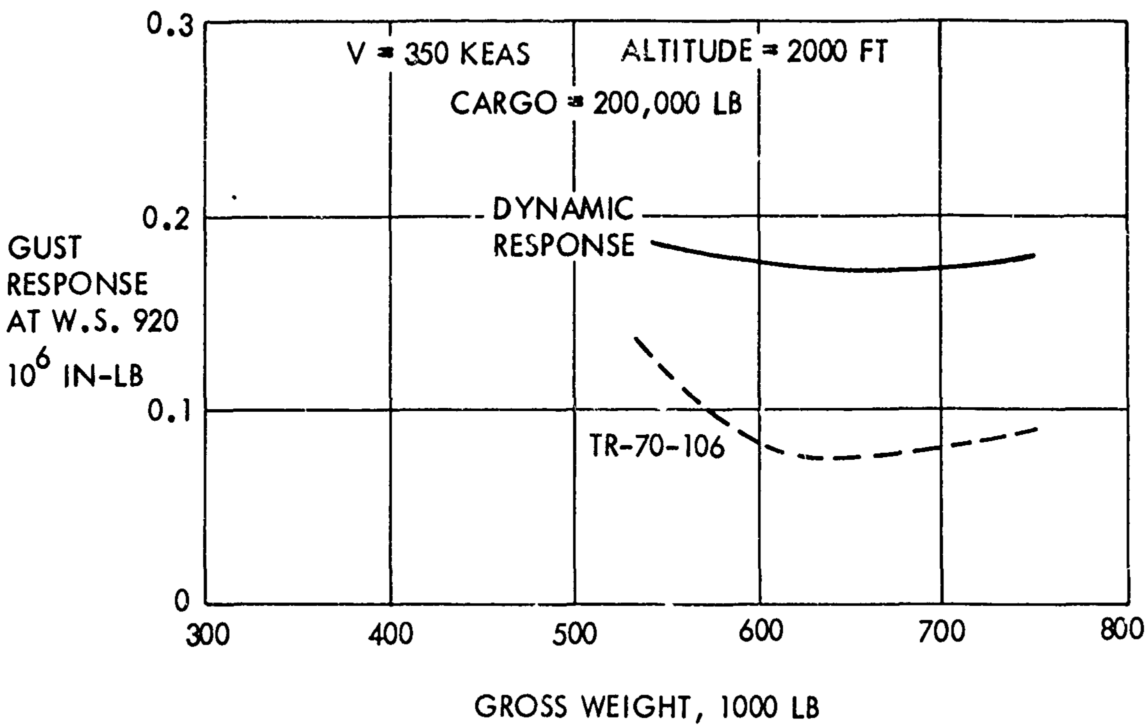


Figure 70 Comparison of rms W.S. 920 Response, C-5A

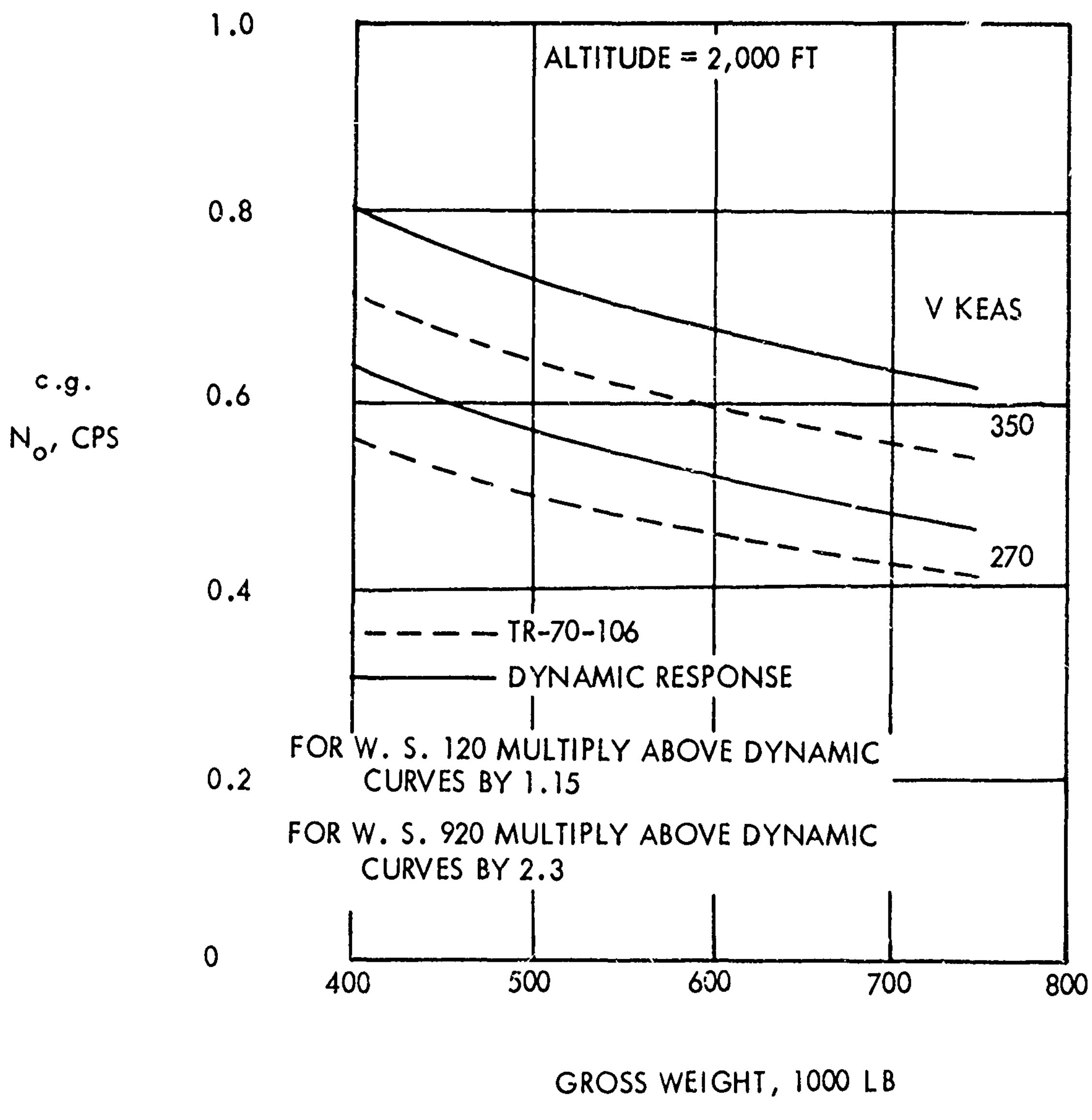


Figure 71 Comparisons of Characteristic Frequencies, N_0, C-5A

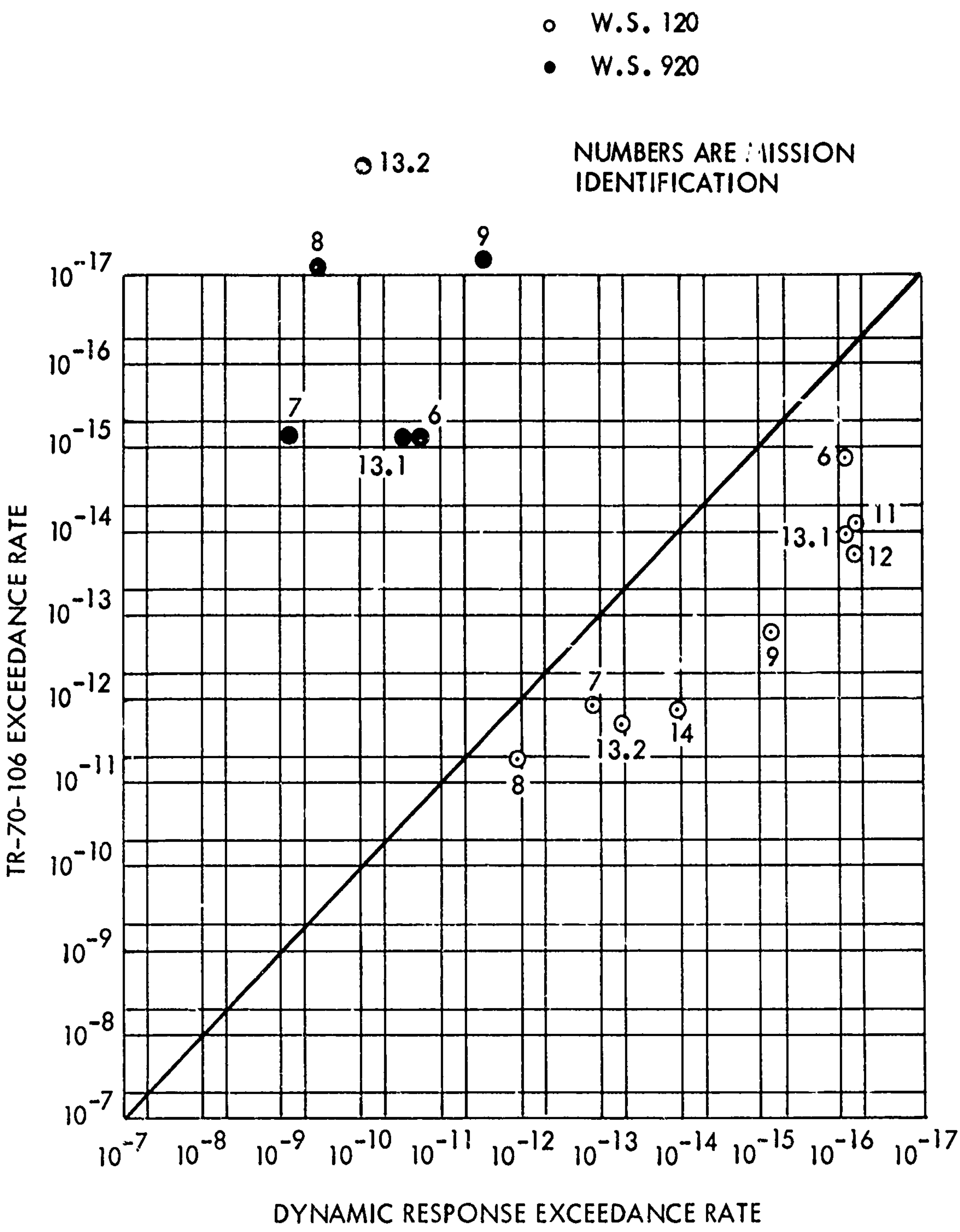


Figure 72 Comparison of Mission Limit Load Exceedance Rate, C-5A

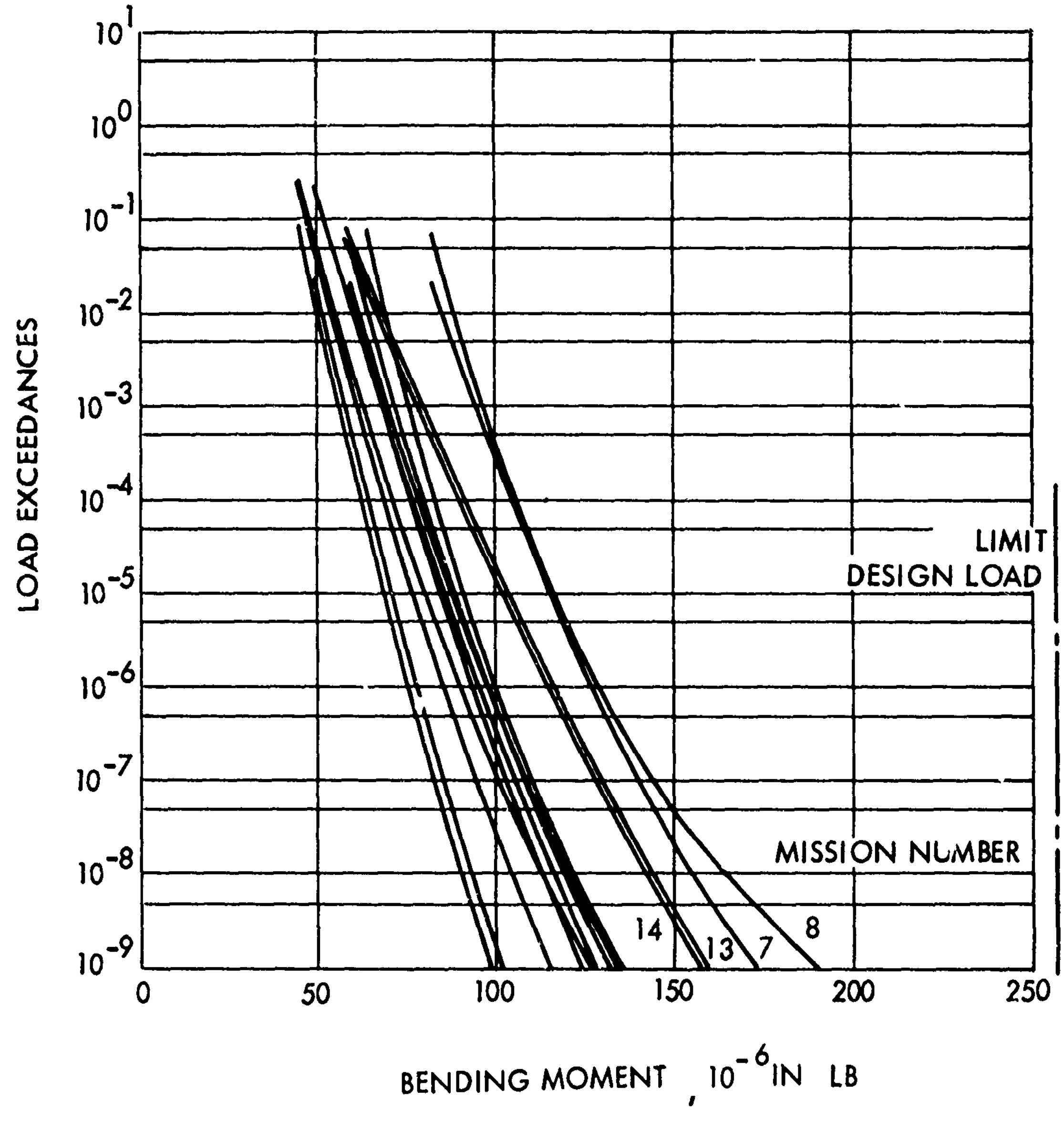


Figure 73 Wing Station 120 Moment Exceedance, C-5A

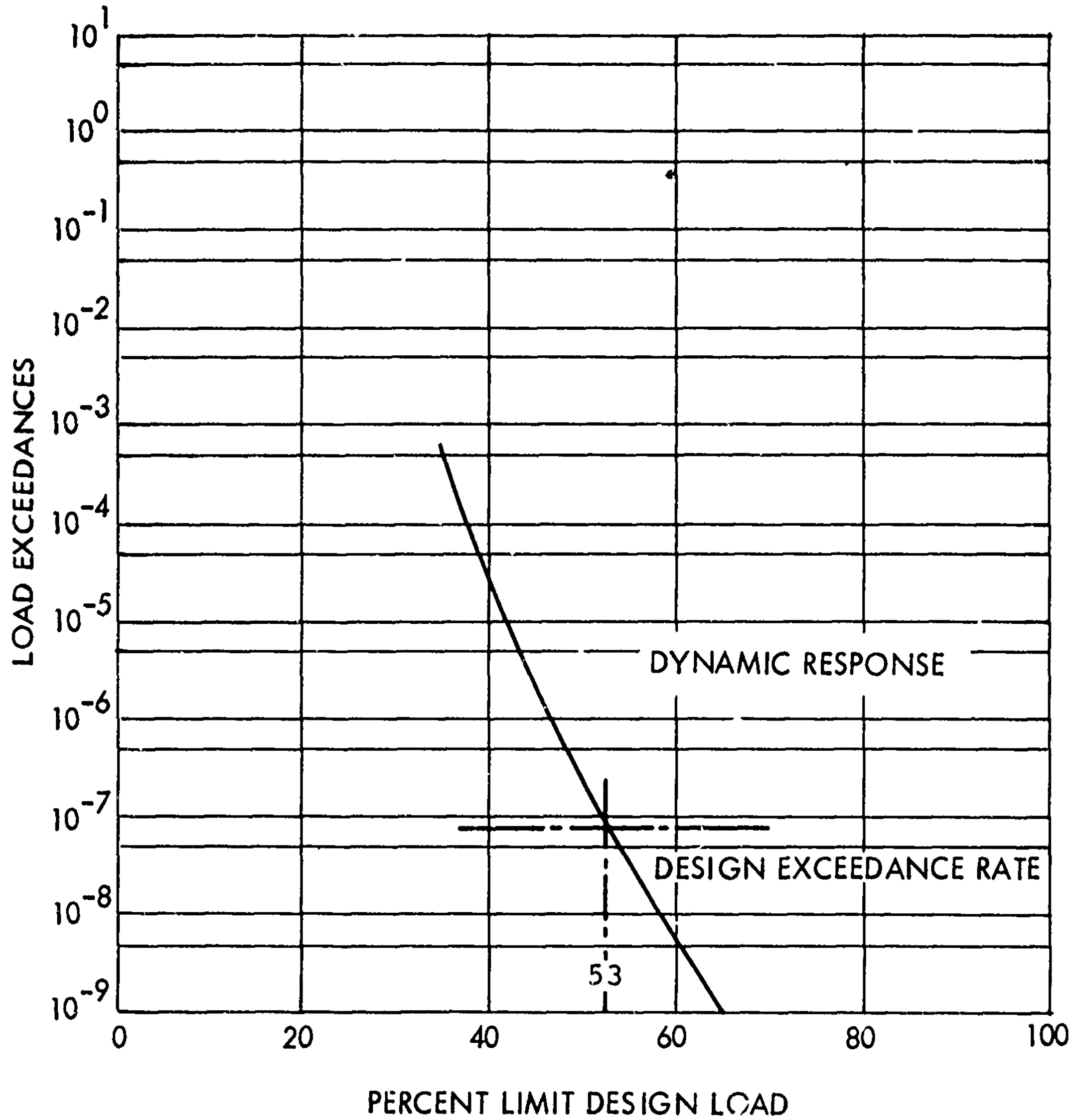


Figure 74 Mission Analysis Design Gust Load W. S. 120, C-5A

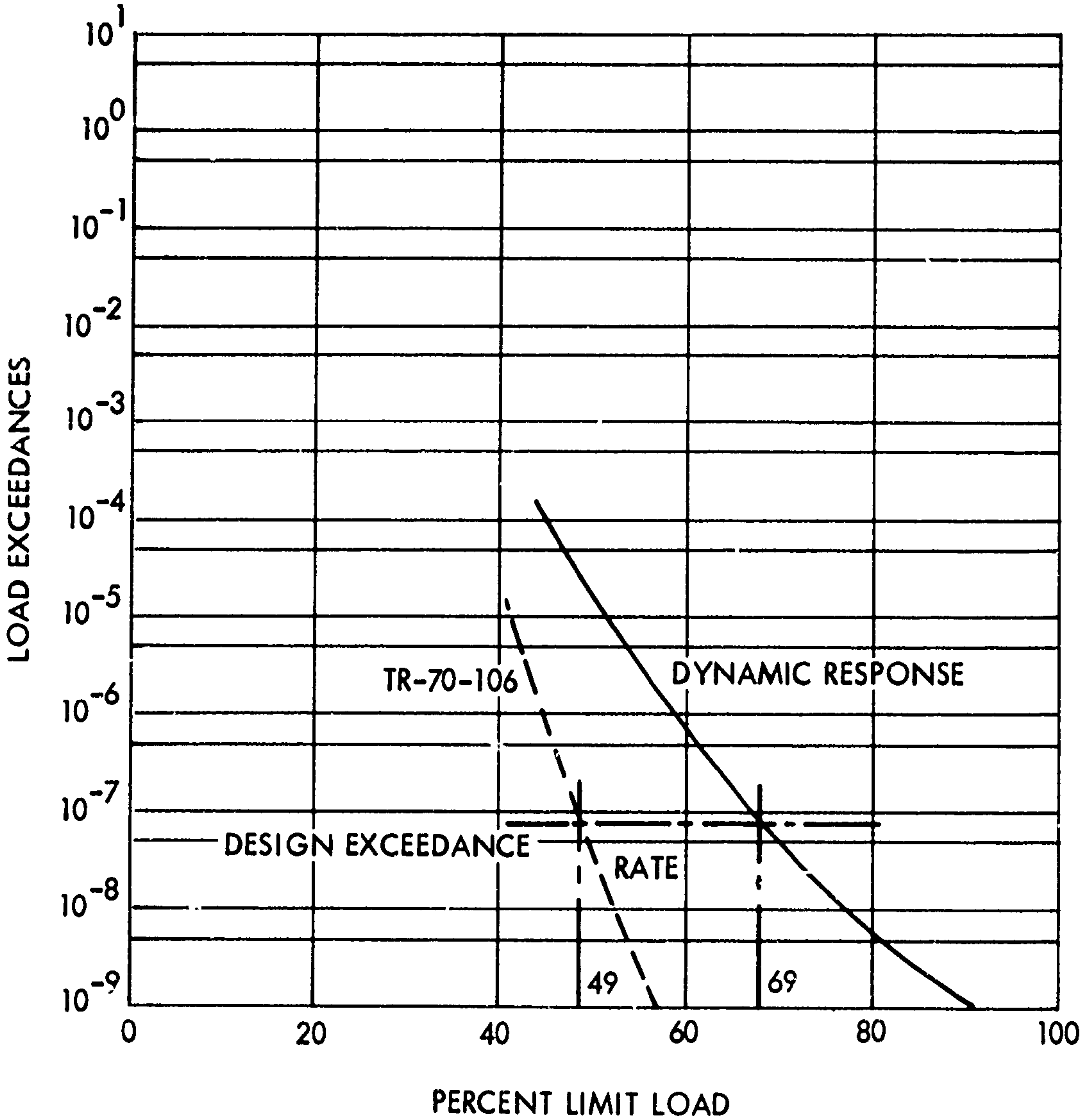


Figure 75 Mission Analysis Design Gust Load Sta. 920, C-5A

SECTION VIII

STUDY RESULTS ASSESSMENT

Design standards for gust encounters are under continuing review and evaluation to ensure continued high levels of flight safety. Early standards assumed rigid body response to a gust encounter of defined shape and intensity. As aircraft continued to grow in size and operated in expanded flight envelopes in terms of speed and altitude, research on response of elastic aircraft to gusts led to various methods of accounting for any increases in loadings due to structural flexibility. Adding these degrees of freedom resulted in load response criticalness as a function of gust wave length or gradient. In attempting to determine the variation in gust gradient with intensity, deciding whether to account for more than the first response peak, and evaluating the criticalness of lowly damped modes (including rigid body) lead to the evolution of power spectral gust analyses.

Implementing design requirements using power spectral techniques has been tedious. First, it is difficult to physically relate to r.m.s. response and power spectrums. Secondly, as data became available numerous sets of turbulence parameters were published. Current standards for military aircraft are different than those used for this study. In addition, definition of the low level contour environment will no doubt continue to hold a dominant influence on gust design. Agreement on gust spectrum and turbulence parameters is still in the future, and design by comparison with existing designs is a convenient method used to validate design procedures and gain confidence in the data.

This report provides data for a wide range of aircraft size and operational flight envelope using a consistent set of parameters and procedures. The response, as determined by the single degree of freedom, is a good approximation of the flexible airframe in an overall viewpoint. Reasonable correlation was achieved when comparison was made with correlated full scale data or analytical frequency response data. The agreement and results are of such a nature that evaluation of frequency response is generally not required. The tacit assumption here would be that aircraft rigid body stability is similar to existing aircraft, that lowly damped modes do not exist or do not result in significant increase in response, and that no adverse coupling

of structural response exists. All of these are true for the study aircraft for vertical gust. It is considered unacceptable to assume no adverse response on a new design, particularly if it is within the state of the art to analyze and evaluate the aircraft frequency response. A primary purpose for doing dynamic analyses is to provide confidence that adverse coupling does not exist. Frequency response and power spectral techniques are the most powerful analytical tools available to explore the unexpected.

The procedure to develop r.m.s. response is easy and readily applied. Design loads and load spectrums for fatigue analyses can be developed readily with confidence that the resulting loadings are representative. It is, therefore, an extremely useful preliminary design tool. In addition, the single degree of freedom method provides a valid base from which to judge results from the frequency response analysis. Expansion of the design manual to include lateral and/or combined gusts would be both desirable and useful.

SECTION IX

REFERENCES

1. Houbolt, J. C., "Design Manual for Vertical Gusts Based on Power Spectral Techniques." Technical Report AFFDL-TR-70-106, December 1970.

2. Houbolt, J. C., "Updated Gust Design Values for Use with AFFDL-TR-106," Technical Report AFFDL-TR-73-148, November 1973.